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COMPILATION AND COMPOSITION OF BITUMINOUS COALS

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A seam or bank of ordinary bituminous coal is readily seen to be stratified; likewise a block or chunk of the same is seen to be highly laminated, and found to be compiled of various layers and sheets of coal differing from one another in color, texture, and fracture, and varying greatly in thickness.[1]

There are generally recognized and described by various authors two kinds of coal with respect to its texture: compact coal and mineral charcoal or mother-of-coal. The former forms by far the larger and the more important part, while the latter forms but a very small, but on account of its nature a conspicuous part of the coal. The mineral charcoal will be considered as unimportant and only incidentally in this paper.

In the compact coal, in general, two kinds of layers are recognizable, apparently alternating and standing in sharp contrast to one another. The one is of a jet-black, pitchy appearance, more compact, and breaking with a concoidal fracture. The other is somewhat grayish in color, of a dull appearance, less compact, and

[1] The figures mentioned in this article are arranged on plates at the end of the article. See Explanation of Plates, p. 206.

breaking with a rather irregular fracture. The former is generally designated as "bright coal" or "glanz coal," and the latter as "dull coal" or "mat coal." On a more careful examination, it is seen that the "bright coal" consists of lenticular masses, greatly varying in breadth and thickness and entirely surrounded by or imbedded in the "dull coal."

It is further found that the "dull coal" is extensively sublaminated into thinner sheets of "bright coal" and "dull coal"; and again on a more minute examination, the bright coal layers are found to be embedded in the dull coal.

The distinction between "bright coal" and "dull coal" has been recognized since the close of the eighteenth century, and many theories have been advanced since that time to explain the phenomenon, but a satisfactory explanation and a true meaning of the alternating dull and bright layers and laminae has never been given.

A condition prevailing generally in all ordinary bituminous coals is well illustrated in Figure 1, representing a small chunk of Illinois coal. In this lump, the "bright coal" is represented by uniform black bands *a*, while "dull coal" is represented by the lighter, finely striated bands *d*. In this respect all ordinary, bituminous coals, no matter from what locality they may be chosen, are similar. Some, of course, like the coal from the Vandalia mine, near Terre Haute, Indiana, possess a larger proportion of "bright coal." Others again, like the coal from the Pittsburgh seam, show a larger proportion of "dull coal"; some seams are all "dull coal," but these are only differences in degree and not in kind.

The sublamination of the "dull coal" is much better illustrated in a vertical fracture slightly magnified, say ten diameters, and especially when such a surface is first smoothed and polished (Fig. 2). The very best illustration, however, is to be had from a thin section, by means of transmitted light and at a low magnification, provided a large enough section is available (Figs. 7 and 10).

Figure 2 represents a part of the surface of the block just shown, limited by the intersecting lines x–x', y–y', m–m', and n–n' and magnified 10 diameters. The bands a-1, a-3, a-5, and a-7 represent

"bright coal," and the bands *d*-2, *d*-4, *d*-6, and *d*-8 represent "dull coal." The lettering in Figure 1 and Figure 2 correspond. It may readily be seen that the bands of "dull coal" are compiled of thin black strips which have a black glistening appearance in the coal, interlayered by a lighter-colored matter which has a dull grayish appearance in the coal and is of a rather uniformly granular nature.

All ordinary bituminous coals thus far examined are similar in this respect and any coal might have been chosen equally well to illustrate this condition.

THE "BRIGHT COAL"

Since the term "bright coal" or its equivalent "glanz coal" is applied to a definite component in coal and has become permanently embodied in the literature, the matter must be treated as a separate subject. In speaking of "glanz coal" or "bright coal" it becomes necessary to limit this designation to those bands or components easily recognizable with the unaided eye, such as are designated by *a* in Figures 1 and 2. Such a limitation draws an arbitrary line between the larger bands easily visible and the thinner ones not so easily distinguishable, and comprising a part of the "dull coal" as already indicated. There is no hard-and-fast line between the two. It is with this restriction that the concept of "bright coal' or "glanz coal" is used at this time.

The question that is constantly raised and that must be definitely answered is, "What are the bands of "bright coal" and what is their origin?" In an examination of Figure 1, although representing but a small piece of coal, it will be seen that a number of the bands of "bright coal" taper off on one end. When a larger block is examined many more will be found to do the same and several may be found to taper off on both ends; and when a very large block or a bank of coal is examined closely almost all, if not all, of the bands of "bright coal" are found to taper off on either end. It may be necessary to follow some of the bands for a considerable distance, many feet possibly, but eventually they terminate in a similar manner. Finally when these are examined in all lateral directions, it can be shown that they taper off in all

directions and hence are lenticular bodies and definite components, and are in reality not layers in the strict sense but lenticular masses.

These components vary, of course, greatly in size and form. Their lateral dimensions may range, as already intimated, from a few millimeters to that of many feet; and in shape may range from that of being approximately equilateral, oval, or circular to that of being many times longer than wide. They are all relatively thin, ranging from a thickness barely visible to that of several inches. But strips of a thickness of more than one or two inches are rare and even such of thicknesses approaching one inch are by no means frequent.

"Bright coal" is anthraxylon.—It is not difficult to show that the so-called "bright coal" are components that are derived from the woody parts of plants, parts that at one time were largely composed of wood. Thin sections were cut, both cross-wise and parallel to the bedding planes, from a considerable number of bands of bright coal from a number of different beds and were examined with the view of determining their origin. Every one examined proved to be derived from some woody plant tissue, either of stem, branch, or roots. In every one the cell structure was well-enough preserved so as to leave no doubt as to its origin. "Bright coal" has yet to be found in which no trace of cell structure is observable.

A good example, representing average conditions of the cell structure is shown in Figures 3 and 5. These photographs represent cross-sections of the woody fibers, or, as it is often called, sections across the grain. It will be noticed that the walls have collapsed and are pressed very intimately together, but that the actual mass of the cell walls has retained most of its original matter. There is, however, a considerable variation in this respect in different components and even in the same components, as is shown in Figure 3. In the upper part of this photograph the cell walls have retained most of their original mass, while those shown in the lower part have become thin and in spots poorly definable, a large part of the cell walls having vanished. In some pieces the remaining tissue resembles that of well-preserved sound wood, except that the walls have collapsed; in other cases again the remaining structure is barely recognizable; the whole tissue has

become homogeneous and the lumena and the middle lamella have been effaced. All possible degrees of preservation may be seen between these two extremes.

There can, therefore, be no doubt that the bright coal represents components derived from larger pieces of woody tissues, such as fragments of stems, branches, and roots now compressed and flattened. In some cases these must have been of considerable size. As it is derived from woody tissues (pieces of wood turned into coal) and consists of definite units easily distinguishable from the rest of the coal, it will be called "anthraxylon," from the Greek *anthrax*, coal, and *xylon*, wood. Bright coal then is synonymous with anthraxylon.

THE "DULL COAL"

Having disposed for the present of the "bright coal" or larger anthraxylon components, closer attention may now be given to the so-called "dull coal" in which the "bright coal" appears to be embedded. It has already been shown when seen in cross-section, that it consists mainly of two kinds of material; thin black bands interlayered by a lighter-colored granular-appearing matter (Figs. 1 and 2). The "dull coal" may, therefore, conveniently be divided into two classes: the thin black strips and its embedding matrix, the attritus.

The dull coal as seen in horizontal cleavage surfaces.—When horizontal cleavage surfaces of any compact coal are examined, a varying number of patches showing woody structures are observed to be distributed over the entire surfaces, surrounded more or less by structureless areas (Fig. 4). These patches vary considerably in size, form, and number. But usually they are relatively small and vary within certain limits. This condition is best illustrated in Figure 4, representing a cleavage surface of the coal from the Vandalia mine, near Terre Haute, Indiana. It represents a horizontal fracture through perfectly compact coal and only a very few of the patches seen represent mineral charcoal. Since this coal splits very readily in any desired plane, very many thin sheets may be obtained and thus many horizontal cleavage surfaces may be produced for observation. All reveal appearances very similar

to the one represented. It will be noticed that the woody patches, about one-half natural size in the photograph, are all relatively small and that in many cases the sides running parallel to the direction of the wood fiber form approximately straight lines, while the sides cutting across the fibers are irregular. Rounded and very irregular patches are not uncommon. The condition so clearly expressed in the Vandalia coal is common, in a more or less varying degree, to all the ordinary bituminous coals thus far examined. The example given may, therefore, well serve as a representative type common to all ordinary bituminous coals.

The patches are solid components.—The question at once arises, Are the woody patches, universally seen on the horizontal cleavage surfaces, merely the impressions of some woody fragments that have long since disappeared or are they actual constituents or components of the coal?

It is not difficult to show that the woody patches represent solid masses on the one or the other side of the cleavage surface. There is, however, for each such component a counterpart patch in the corresponding cleavage surface, which is an impression. On cutting with a fine, sharp tool into the patch representing the component, a thin glistening layer of coal is found immediately underneath the surface over the entire patch. Also when a lump of coal is submitted to Schulze's maceration reagent for a certain length of time it may be brought into a condition in which it readily separates into numerous thin, scaly fragments. Many of these bear the woody structure on both sides and when broken show glistening, glassy, jet black coal in the interior. Or, after a treatment for a certain length of time with this reagent, a small lump of coal may be dissected and there may be isolated small sheets or scalelike masses bearing woody marks on the surfaces and consisting of bright glistening coal in the interior.

In splitting a lump of coal it is very rare that the fracture runs through the middle of these thin components, but almost always along one of its surfaces. The larger components of bright coal or larger anthraxylon elements, on the other hand, almost always split through the interior, exposing glistening jetty coal of the same appearance as that in the thin components.

The components seen as patches in the horizontal cleavages and the thin black bands seen in the vertical sections are identical.—The next question arises, "Are the components seen as patches on the horizontal cleavage surfaces as shown in Figure 4 and the black, thin bands seen in cross-sections of the 'dull coal' as shown in Figures 1 and 2, and Figures 7 and 10, identical?" This question can also be definitely answered in the affirmative. A piece of coal, small enough to be placed under a dissecting microscope, may be split horizontally with a sharp tool through any desired lamina; and when thus carefully manipulated it may easily be shown that the black bands seen in the cross-section are the thin, flat components seen on the horizontal cleavage surfaces.

The thin black bands are anthraxylon.—On account of the woody structure present on the surfaces of these components, it must at once be inferred that they are also derived from fragments of woody tissues. The correctness of this inference must be demonstrated so as to leave no doubt.

Correlation of opaque sections with thin sections.—In order to make the demonstration easier and more convincing it is desirable to correlate the appearance of the opaque surfaces of the coal, either at macroscopic observation or at a low magnification in which the characters have already become familiar, with the appearance of thin sections observed by means of transmitted light.

Figure 7 represents the appearance of the cross-section of "dull coal" of an Illinois coal as seen by means of transmitted light at a low magnification. This should be compared with Figure 2, previously referred to, taken from an opaque section of the same sample of coal and at the same magnification, but by means of reflected light. The darker bands in Figure 2, which have been shown to be the components seen as patches on the horizontal cleavage surfaces, correspond to the lighter, more homogeneous-appearing bands interlayered by the heterogenous-appearing laminae shown in Figure 7.

Figure 7 shows numerous strips of thin "bright coal." Figure 8 shows a part of the same at a much higher magnification and plainly shows plant structure in all, but particularly in the strip *a*-1.

Figure 9 is a random horizontal section of coal from the same bed showing that woody structure is present everywhere.

The illustrations given represent the average conditions of most coals in which it is not difficult to detect, in any cross-section, plant structures in most of the strips in question. In some coals, like that from the Vandalia mine and that from Buxton, Iowa, it is not so easy to detect structures so readily in cross-sections. In the horizontal sections, however, plant structures are invariably revealed.

The coal from the Vandalia mine near Terre Haute, Indiana, as shown in Figure 10, at a low magnification is compiled of innumerable thin strips separated by very thin layers of attritus. Cross-sections, at a higher magnification, are shown in Figure 11. The bands *a*-1, *a*-3, and *a*-5 represent some of the thin strips seen in Figure 10. There is very little in these that resembles plant structure. In the horizontal sections, on the contrary, no matter where cut, it is clearly shown that these strips still bear a profusion of plant structure as seen in Figure 12. Of all the coals examined the Vandalia coals contain the poorest preserved structures. Similarly in all coals there are many strips in which at a casual observation no or little direct plant structure is noted, but when such specimens are examined in horizontal sections, plant structure is invariably found to be present. There is, nevertheless direct evidence of such structure almost always observable in cross-sections in the great majority of strips. It will be noticed that most of them have a finely striated or fibrous appearance and this structure is due to the remaining plant structure in the strips. This structure becomes recognizable in the horizontal sections and hence is a direct evidence of cell structure.

A large number of horizontal sections have been prepared from a considerable number of coal seams and in every case cell structure still existed in these thin laminae. The evidence may be considered conclusive.

There exists, therefore, little doubt that the thin bands of bright coal forming a large part, and in many the largest part of the dull coal of ordinary bituminous coals, are also derived from the woody parts of plants. But instead of representing larger parts of plants

they represent only small fragments or chips of the same. The thin strips of "bright coal," therefore, are also anthraxylon components.

Origin of the small anthraxylon components.—It is interesting to know why so large a bulk of the coal should exist in the shape of these thin but relatively wide or broad anthraxylon chips. This question is readily and satisfactorily answered by analogous conditions in peat. Furthermore, a study of these chips of wood in peat lends at once, by analogy, a proof of the woody origin of the anthraxylon components in coal and form a picture as to what may have taken place in the peat bogs of the Coal Age.

In examining a peat deposit such as had its origin in an arboreal growth (Fig. 13), it is discovered that a large proportion of the woody matter consists of thin scaly chips, as shown in Figure 14, which may easily be separated from the peat. As shown in Figure 15, they consist of very thin tangential shells and thin radial plates.

The larger stems and branches of the fallen trees while still above the surface of the deposit become partially decayed. The tissues, having thus become very much weaker along the spring wood of the annual growth rings where the cells are large and the walls relatively thin, are apt to separate along this area, peeling off as thin tangential sheets at the slightest disturbance. A semi-decayed stem of the basswood, Tilia Americana, is a well-known example with a tendency to peel off in this way. Sheets of semi-decayed wood of that nature break up very readily into smaller and still thinner chips. Conifers also have a tendency to peel off in this manner. In trees with broad rays like the oak, the weakest areas are formed along planes parallel to the medullary rays and the tissues will separate into thin radial plates instead of tangential scales or shells. Through either mode of disintegration numerous thin and relatively broad plates or scaly chips of semi-decayed wood are formed. These constitute a very large proportion of the peat. A similar mode of disintegration must have taken place in the peat stage of the Paleozoic coals, as the small anthraxylon chips in coal indicate. The chips in coal and the chips of woody peat in peat are similar.

The kinds of tissues represented in the coals.—In an examination of a considerable number of sections from a number of coals, it is learned that by far the larger proportion of the tissues remaining represent woody parts of plants. By woody parts of plants is meant parts of stems, branches, twigs, and roots, including all the tissues, except the bark, that goes to make up such a part of the tree or shrub. It cannot be said with certainty that the bark has contributed to any extent to the constituents in question. If bark is present at all in coal it finds its recognition possibly in components appearing altogether different, which will be discussed later.

The anthraxylon of the dull coal then is derived for the most part from rather small chips of semi-decayed woody tissues, such as are prevalent in the peat bogs of today. Prosenchyma or wood proper, and parenchyma such as cortex, pith, and rays are all met with and are clearly distinguishable. There is, nevertheless, no doubt that some of the structure seen in thin sections is derived from the more succulent or younger parts of plants as well as from herbaceous plants. Leaf-strands with some of the accompanying tissues, petioles, and other vascular strands are frequently detected. What appear to be delicate tissues of plants are frequently seen. The parenchyma of leaves is rarely observed, yet occasionally structures are seen that could be construed as having been derived from leaf parenchyma, and in some cases certain structures represent without a doubt leaf tissues in which all the leaf tissues, particularly the palisade cells, are well represented, and may be favorably compared with the leaf tissues of a living Cycad. In most cases the tissues contained between leaf cuticles have been disorganized beyond identification. Occasionally tissues are found in a fairly good state of preservation which as yet cannot be correctly classified. In this connection spore walls or sporangia should also be mentioned. Sporangial walls, either singly or in connection with remainders of cones, are a common occurrence in most coals, but particularly abundant in the coal from Buxton, Iowa. Such spore walls are often remarkably well preserved. A considerable amount of the woody tissues as well as other plant tissues have been reduced to a finer state of division, exactly as is

the case today in the peat deposits, and hence are classed with the attrition matter and will be discussed under the attritus.

Cuticles.—The outermost layer of tissues of all leaves, petioles, green parts of young stems, twigs, fruit, and seeds of plants, consists of tabular cells very closely united and uninterrupted except by stomatal pores. This is the epidermis. In some plants it persists with but little change; in others it is thrown off sooner or later and replaced by a layer of cork. Delicate epidermis possesses thin walls; but in a large number of plants with fleshy and tough leaves, the walls are of considerable thickness.

The exposed surface of all epidermal cells are covered with a layer of cutin forming a continuous transparent film or membrane over the entire surface of leaf or stem. This film is called the cuticle. It is present on all leaves, pedicles, green or young stems, twigs, fruits, berries, and sometimes persists on older stems and branches. Often the cuticle is further covered with a waxy and resinous matter. In some cases the amount of such substances is large and assumes commercial importance, as in the wax palm (Ceroxylon andicola) and the bayberry (Myrica cerifera). The waxy coatings may be in the form of coherent layers or incrustations upon the cuticle; in crowded vertical rods, sometimes of considerable length; in very short rods or rounded grains, very much crowded on the leaves of some plants; or in minute grains or minute needles.

The cuticle is very resistant to putrifying organisms and persists under peat-forming conditions after most of the underlying tissues have been disorganized or have disappeared. Cuticles or fragments of cuticles are always present in peat, occasionally in large proportions.

Cuticles in coal.—Similarly in coals a large amount of cuticular matter and some cuticularized tissues have survived and are ever-present constituents, often forming very appreciable proportions of the dull coal (Fig. 16).

In thin sections, under the microscope, the cuticles appear as bright golden-yellow bands of considerable length but relatively narrow. One edge is usually smooth while the other is usually saw-edged. Frequently they are found in pairs with the same-edged

sides toward each other. Figure 17 is taken from a section containing a large proportion of cuticular matter very similar to that shown in Figure 16. Here the cuticles are represented by comparatively heavy light-colored bands, sometimes in pairs embedded in a general débris derived largely from leaves and other vegetable matter. Cuticles are sometimes accompanied by well-preserved leaf tissues. Cuticular matter is also present in a macerated or more or less fragmented condition. When in this condition it forms a constituent of the attritus, and is often difficultly distinguishable from fragmentary spore-exine matter which it closely resembles in color and general appearance.

Like the spore-exines the cuticles may very easily be separated from the coal by means of Schulze's reagent. When thus separated from the coal they appear as tissues or films constructed of cells (Fig. 18). They are, however, non-cellular, hyaline membranes and the apparent cell structure is due to ridges on the under surface that conformed to the once underlying epidermal tissue. In cross-section these ridges give the saw-edged appearance. A considerable number of patterns of the apparent cell structure, or in other words, different types of cuticles, are found, thus indicating that a number of different species or genera of plants are involved.

BARK

It cannot be said with certainty that bark has contributed any appreciable amount to coal; nothing has been met with that could be referred to with certainty as derived from bark. There is, however, a constituent reoccurring in all coals, most frequently in the coal from the Pittsburgh seam, that might be interpreted as being derived from bark. It is shown in Figure 6. This component is always of a dark-brown color, lumpy, porous, and of irregular structure. By far the largest proportion of it has retained some of its original plant or cell structure. On the whole, the remaining cell structure is very poorly and very irregularly preserved and appears to be derived from large-celled tissues. It almost always includes a large number of resinous-appearing globules, and frequently also more highly carbonized matter. It also frequently includes parts of the tissues, or strands of tissues, in which the plant structure is still well preserved. In some of

the components the whole mass is fairly well preserved and then again, components are met with in which the whole mass is disorganized and consists of irregular fragments, but always of the same color and general appearance. Frequently the component is composed of bands of more or less well-preserved tissues alternating with bands of disorganized, granular matter.

The components vary largely in size as seen under the microscope, ranging from but tiny bits to good-sized masses. There is also a wide range of transparency in them, both in different components and in different parts of the same component. The most transparent ones are of a dark-brown color in thin section, but opaque in medium-thick sections.

This component, possibly derived from bark, is characteristic through its brownish red color in thin section, irregular structure, lumpiness, and relative opacity, and is easily distinguishable from the rest of the coal. Although in some layers or laminae it may be quite abundant, yet, on the whole, it forms but a small part of coal.

The attritus.—It has been shown that the larger anthraxylon components or bands of bright coal are embedded in the dull coal; and in turn that the dull coal consists largely of smaller anthraxylon constituents together with a few other constituents such as cuticles and barklike constituents, embedded in a general matrix, the attritus.

At low magnification, the attritus appears as a uniformly granular, amorphous mass (Figs. 2, 7, and 10). At a higher magnification, it at once appears as a very heterogeneous substance. Typical appearances of the attritus in cross-section are shown at *d*-2 and *d*-4 (Fig. 11); at *d*-1, *d*-3, and *d*-7 (Fig. 19); at *d*-1, *d*-3, and *d*-5 (Fig. 20); and in horizontal section in Figures 22, 24, and 25. A close examination at a high magnification will at once reveal that it is composed of a number of groups or classes of constituents, most of the members of which are specifically and definitely definable and their origin determinable. These are cellulosic degradation products or humic matter, spore-exines, resinous matter, cuticular matter, more highly carbonized matter, certain small bodies usually designated as rodlets or needles, and some mineral matter.

The humic matter, or cellulosic degradation products.—In the photographs just referred to, particularly noticeable at *d*-1 (Fig. 19), there will be recognized besides the strips designated as anthraxylon constituents, other strips similar in appearance but thinner and more irregular in width and bearing no marks of plant structure. Besides these, there are other more globular constituents, some of very small sizes, others very finely divided. These are of the same general appearance and color as the anthraxylon matter and constitute part of the attritus. Most of this matter evidently is of the same general origin as the anthraxylon components, and may be collected into one class and designated under the general term of "humic" matter. Under "humic" matter then is considered the cellulosic degradation products in a state of division finer than the smaller anthraxylon components but not including resinous, cuticular, spore, or carbonaceous matters. There is no hard-and-fast line of distinction between the smaller anthraxylon components and the humic matter. The particles constituting the humic matter in general no longer bear visible marks of plant or cell structures and are smaller in sizes.

It should be emphasized that the humic matter consists very largely of definitely definable particles and not of a vague plastic or homogenous mass, and only a comparatively small proportion is so finely divided as to lose its individuality even under very high magnifications. When this stage is reached, we enter the realm of colloidal conditions, and proper methods will here also show that the matter consists of individual particles.

There must be included in the term humic matter, substances of a wider origin than the anthraxylon, such as gums, pectins, cork, bark, and other substances closely allied to the cellulosic materials. In analagous studies of peat, where the constituents are more easily identified, there is very little matter that is of other origin than cellulosic; and if the formation of coal and peat is to be considered analogous, the conclusion must be drawn that but a small proportion of the humic matter in coal can be other than of cellulosic origin. This, however, does not dispose of a long list of substances known to exist in plants, such as tannins, alkaloids, oils, terpenes, camphors, etc.; but if these or their derivatives are still present

it is very likely that they are present in an absorbed condition; that is, absorbed by the anthraxylon and other constituents, and so will have lost their identity under the microscope. In the peats, many of these substances may be detected by microchemical means, and are found to be absorbed mostly by the woody constituents, but ordinarily are not visible under the microscope.

Since there are no, or at the most very few, plant structures remaining in that part of the coal classed under the attritus, the origin of all its constituents, with the exception of the spore-exines, cuticular matter and certain resinous matter, cannot be as closely defined as the anthraxylon matter. Though much of this matter is clearly shown to be woody degradation products, yet it is highly possible that a considerable amount of bark and cortex is included. As has been stated before, bark, that is, that part of the tree or plant usually designated by that term, has not been recognized positively in the coals examined. Cortex, pith, and parenchyma have been recognized comparatively speaking in small quantities. The conifers of the Paleozoic times probably were the only trees with true bark, and the bark of these undoubtedly disintegrated similarly as that of the peat-forming trees and shrubs of the present, and this largely lost its identity and still exists as humic matter.

The spore-exines.—The spore-exines (Figs. 27–41) are ever-present constituents, and no coal is entirely free from them. Even the coals with the least number of spore-exines, like the Vandalia coal from Indiana, contain a considerable amount of spore matter. Under the microscope, in thin section, they are the most conspicuous objects in the coal, due to their clear yellow color and transparency. In the photographs, representing cross-sections, at a magnification of 200 diameters, they may be recognized as very small linear patches (Figs. 19 and 20). At higher magnifications, say at 1,000 diameters (Fig. 21), their true nature is more clearly shown. Here they appear, when whole, as collapsed rings, being in reality collapsed spheres, and merely represent the outer shells or spore walls or exines of once living spores of the Paleozoic plants that evidently also contributed to the coal themselves. Its contents, such as nuclei, protoplasm, chloroplasts, and inner spore

wall have disappeared completely, or almost so. In the photographs at 200 diameters prepared from horizontal sections (Fig. 22), the spore-exines are shown on their broad side, and appear as circular to oval or slightly triangular disks. At a higher magnification, say at 1,000 diameters (Figs. 24 and 25), the characters, such as form, sculpturing, and tetrasporic marks remaining on the exines, are clearly shown.

An excellent way to study the spore-exines is to macerate the coal by means of Schulze's reagent and digest it with ammonia. The spore-exines and cuticles are left undissolved and apparently unchanged. Figures 27–41 show some of the spore exines thus isolated.

From a collective study of all the spores, it is evident that a considerable number of species and genera of plants contributed to the spore matter in coal. Two distinct types of exines are distinguishable. The one is always in the shape of a circular disk, in some cases tending to be triangular and less often tending to be oval or ovoid, and all bear the familiar tetrasporic mark. These are the exines of Paleozoic Pteridophytes. The other is always oval or ovoid, but does not bear the tetrasporic mark and has a long slit parallel to the long axis of the oval; often with a second short slit at, or toward, one of the extremities. The surface is apparently smooth and unsculptured (Figs. 25 and 30). These are undoubtedly the exines of the pollens of certain Paleozoic Gymnosperms.

The exines of true spores.—On the whole, the true spore-exines are much more abundant in coal than are the exines of pollen grains. There is a large range of sizes among them, from that of only about 10 microns (Figs. 22 and 24) or $\frac{1}{100}$ of a millimeter, to that of 2 and 3 millimeters in diameter (Fig. 38). There are to be recognized two kinds: megaspores and microspores. From a biological standpoint, three kinds should be distinguished: megaspores (Figs. 35 and 38), microspores, and neutral spores. This is not only a distinction of size, but also of function. Megaspores in living plants are always large and on germination produce male gametophytes; microspores are always relatively small and produce female gametophytes; while certain other spores, classed among

the smaller ones, may produce gametophytes that may reproduce either male or female gametophytes, there being apparently no predetermination. Among the spores of the coals, no such distinction can be made, and all that can safely be said is that some are large and others are small, and assume that the larger ones are megaspores; but between the spores that functioned as microspores and those that are neutral, no distinction can be made, and the term microspores must apply to both kinds, if used at all. This affords a convenient, if not exact, distinction, between the very large spore-exines and the smaller ones. It should be stated that the range in sizes is gradual from the smallest to the largest, and that no fast line, in regard to size, can be drawn between the two.

The thickness of the exine walls varies very greatly with the kind of spore from which derived, and ranges from the tinest film of only a few microns in thickness to such where it is a huge mass of a hundred microns or more, as in the large megaspores as shown in Figure 38. But the size of the spore is not always commensurate with its thickness. Very large spores are observed with but very thin walls, and again comparatively small exines are met with which have walls equal in thickness to half their diameter.

Almost all spore-exines are sculptured, and only comparatively few are smooth, and each kind has a definite type of sculpturing, which affords a ready means of distinction between them. The sculpturing may take a variety of forms and may consist of serpentine ridges, irregular elevations, echinate protuberances, sharp, slender spines, and short hairlike coverings. In many cases, these are arranged in definite order, as in spirals or rows (Figs. 27–41). Some exines are covered all over with a ramentum; others bear a long tuft of ramentum on a small area only; others have a number of long slender wings; and still others have three large air sacks.

Exines of pollen grains.—A large number of exines present in coals are apparently those of pollen grains (Figs. 25 and 30). In a very large number, especially noticeable when they have been isolated from the coal by means of Schulze's reagent, there is a long slit running parallel to the long axis of the oval; and

frequently with a short cross slit at or near one of the ends of the longitudinal slit, but a tetrasporic mark is never seen. The absence of the tetrasporic mark and the presence of a slit then are characteristic characters. In color, transparency, and consistency they are similar to the true spore-exines. Their surface is always smooth and has no spines, processes, or hairlike coverings. They vary greatly in size, indicating that a considerable number of species or genera of plants are involved. Compare Figures 25 and 30, photographed at the same magnification.

The resinous matter.—There are universally scattered through or contained in the attritus of all coals, certain particles, which, when seen under the microscope, are generally of a more or less rounded or ovoid form, rarely angular or irregular; of a rather homogeneous or vitrious consistency; of a brownish red to red color, a color very similar to that of the anthraxylon components and the humic matter, called resinous particles. Such form a very appreciable part of many coals. These constituents are classed under resinous matter, because they resemble very closely certain constituents in peat and lignite where they are more certainly known to belong to the natural resinous substances of plants. Many of the resinous-appearing bodies in the attritus, moreover, very closely resemble certain bodies still included in the original tissues of both the smaller and the larger anthraxylon components. Further, there are clear cases of transition from where they are still included in the original tissues to that where they are free in the attritus.

There is, therefore, enough basis for assuming that the constituents in question are derived from the natural resins of the Paleozoic plants. The proof is, nevertheless, not as positive as one would like to have it. But since the constituents in question stand in quite sharp contrast to the other constituents and are tolerably well definable into a distinct class of components, the term applied to them is believed to be justifiable. Besides, it affords a convenient means to distinguish them from the other constituents.

Good illustrations of resinous matter in the attritus are given in Figures 23 and 26, also in Figure 19. Figure 26 shows

exceptionally large amounts of it, but layers with equal amounts are not rare in any coal.

The carbonaceous matter.—All ordinary bituminous coals contain certain constituents that are more highly carbonized than the rest of the coal and to which it stands out in sharp contrast on account of their opaqueness. These are well represented in Figure 22, in which these constituents are represented by the more or less irregular black areas. They are also seen in Figures 19 and 20, 21, 24, and 25.

In general, there are two types of carbonaceous matters: one shows definite plant structure and is clearly shown to be more highly carbonized parts of plant cells or bits of woody or other plant tissues, and the other shows no plant structure and is of indefinite origin.

The former usually have retained the original plant form and characters, such as pores, pits, trabacular and spiral thickenings. These are nothing more or less than smaller bits of mineral charcoal. The different constituents of this class of carbonized matter vary largely in the degree of carbonization and hence also in opaqueness. Its opaqueness varies from that where it is only slightly more opaque than the normal anthraxylon constituents to that where it is entirely opaque even in the thinnest sections. In general, however, most of it is opaque in the medium thin sections, becoming translucent in the thinner sections. Relatively very few appear to be entirely opaque in the thinnest sections. When translucent or transparent, they are of a dark-red color, becoming darker with increase of opaqueness and of a lighter red with decreasing opaqueness, approaching a pale yellowish red in color.

The disorganized opaque matter.—The other kind, the disorganized and more irregular kind of opaque matter, is not so easily defined. Its origin is possibly varied, but most of it is of undoubted organic origin. The shape of most of the particles comprising the matter is irregular, but a considerable number are oval to spherical. In size they vary from the most minute particle to that visible to the naked eye. The more spherical and oval particles suggest carbonized resinous matters.

Rodlets.—Other constituents that are invariably present in all coals are the so-called rodlets. Generally speaking, they form

but a small part of any coal, but they are much talked about on account of their conspicuousness and prominence in the mineral charcoal and on the cleavage surfaces. They are called rodlets because they have the appearance of minute rods. By some they are also called needles, because of their slender needle-like appearance. In cross-section, the rodlets appear as circular to oval disks of a dark color in very thin sections; in thicker sections they are opaque. They are of a relatively large size when compared with spores and pollen grains.

Many of the rodlets are scattered helter-skelter through the attritus (Fig. 43). In some laminae they are present in large numbers, and in such cases, form a large proportion of the coal. Many of the anthraxylon components (Fig. 44), and, conspicuously, many of the mineral charcoal constituents, inclose many rodlets that are evidently part of their structure or tissue. Some of the tissues in coal with which rodlets are associated may be classified with the Medullosae (Fig. 44), well-known Paleozoic plants allied to the Gymnosperms. The cortex of the Medullosae is known to have been pervaded by gum or mucilage canals. In a specimen at hand of Medulosa Anglica (Fig. 42), these canals are still filled with a dark solid substance. These solids resemble very closely certain rodlets embedded in the attritus, as well as those associated with anthraxylon components.

The rodlets are non-resinous, give off a blue non-sooty smoke on burning, do not swell or puff up, and do not become viscous when heated. They are of a black, glistening, glassy consistency, breaking with a decided concoidal fracture. When burned, they leave a very delicate, finely grained skeleton of quarts, the relative amount of which varies very largely in different rodlets. In some it forms a very delicate skeleton, while in others there remains a solid mass almost as compact as was the rodlet before burning, except that it is now snowy white. Between these two extremes, all possible intergrades may be observed. In fact, some rodlets consist of almost pure white quartz. Some have a core of quartz surrounded by a shell of black matter.

It seems clear then that some of the rodlets, if not all, are the semi-petrified or petrified contents of the mucilage canals of certain Cycadofilicales, like Medullosa.

SUMMARY

The bituminous coals consist of alternate layers of "bright" coal and "dull" coal. The "bright" coal is called anthraxylon.

The "bright" coal was formed from the large limbs and trunks of trees or parts of them which were not disintegrated in the peat swamps previous to the formation of the coal. This "bright" coal retains its original woody structure, although often somewhat distorted.

The "dull" coal consists of numerous small layers or chips of "bright" coal embedded in a dull matrix, the attritus. These small chips of anthraxylon are derived from the chips, splinters, small stems and branches, twigs, roots, etc. Possibly part of the large woody chunks slightly disintegrated, due to the incipient decay previous to the formation of the coal, and thus provided some of the small layers of "bright" coal. No bark entered into the formation of the small layers of anthraxylon.

The dull matrix or attritus, in which the small layers of "bright" coal are embedded in the "dull" coal, was derived from the following sources:

a) The waxy cuticle covering of the leaves. This is an extremely resistant substance and remains in the coal in narrow, yellowish, semi-transparent bands of varying lengths.

b) Spore-exines. These vary from 0.01 mm. to 3 mm. in cross-section.

c) Pollen exines.

d) Resinous matter. This is the original resinous substance of plants.

e) Small particles of resinous and woody matter from a highly carbonized state down to a little carbonized state.

f) Small rodlets or needles. These are possibly the petrified or semi-petrified gum or mucilage canals that pervaded the cortex of some Paleozoic plants. On burning, they leave a white quartz skeleton.

g) Small amounts of gums, pectins, and corks.

The tannins, terpenes, alkaloids, etc., if still present, are absorbed in the coal and do not show up microscopically.

EXPLANATION OF PLATES

PLATE III

FIG. 1.—A block of Illinois coal from vein No. 6. The black bands *a* represent anthraxylon, the grayish bands *d* represent the layers of "dull coal." The area described by the intersections of the lines *x*–*x'*, *y*–*y'* and *n*–*n*, *m*–*m'* is the same area shown in Figure 2, and bands *a*-1, *d*-2, *a*-3, *d*-4, *a*-5, *d*-6, *a*-7, and *d*-8 of the one are correspondent to the other. The lenticular band "CO" represents a cone of Lepidodendron. Natural size.

PLATE IV

FIG. 2.—The area described by the lines *x*–*x'*, *y*–*y'* and *n*–*n'*, *m*–*m'* in the block of coal shown in Figure 1, and enlarged 10 times. The bands *a*-1, *d*-2, *d*-4, *a*-5, *d*-6, *a*-7, and *d*-8, representing alternate layers of anthraxylon and "dull coal," of the one being correspondent to the other. ×10.

PLATE V

FIG. 3.—A part of a thin cross-section of "bright coal," or anthraxylon, showing more or less well-preserved structure of wood. ×200.

FIG. 4.—A horizontal cleavage surface of compact coal from the Vandalia mine near Terre Haute, Indiana, showing patches with woody structure or anthraxylon chips, more or less surrounded by structureless areas representing the attritus. "Needles" are also shown. ×200.

FIG. 5.—A part of a thin cross-section of "bright coal," or anthraxylon, with resinous inclusions. ×200.

FIG. 6.—Part of a thin cross-section of coal from the Pittsburgh seam, consisting of a constituent that may be bark. The tissue is large-celled, irregularly preserved, including a considerable amount of resinous matter. ×200.

PLATE VI

FIG. 7.—Part of a thin cross-section of coal from Royalton, Illinois, at a low magnification, showing numerous thin chips of anthraxylon, more or less separated by thin layers of attritus. × 10.

FIG. 8.—A part of the thin section shown in Figure 1, at a higher magnification. Some of the anthraxylon chips have retained their cell structure to a remarkable degree, a common occurrence in most coals. × 200.

FIG. 9.—A part of a thin horizontal section of the coal from Ziegler, Illinois. A random section; the plant structure shown is of common occurrence in any horizontal section. Anthraxylon chips are seen on either side. The circular to oval spots in the attritus in the center represent spore-exines. × 150.

FIG. 10.—Part of a thin cross-section of the coal from Terre Haute, Indiana, at a low magnification. The numerous grayish bands or strips represent anthraxylon chips; the darker mottled matter between these represents the attritus. × 10.

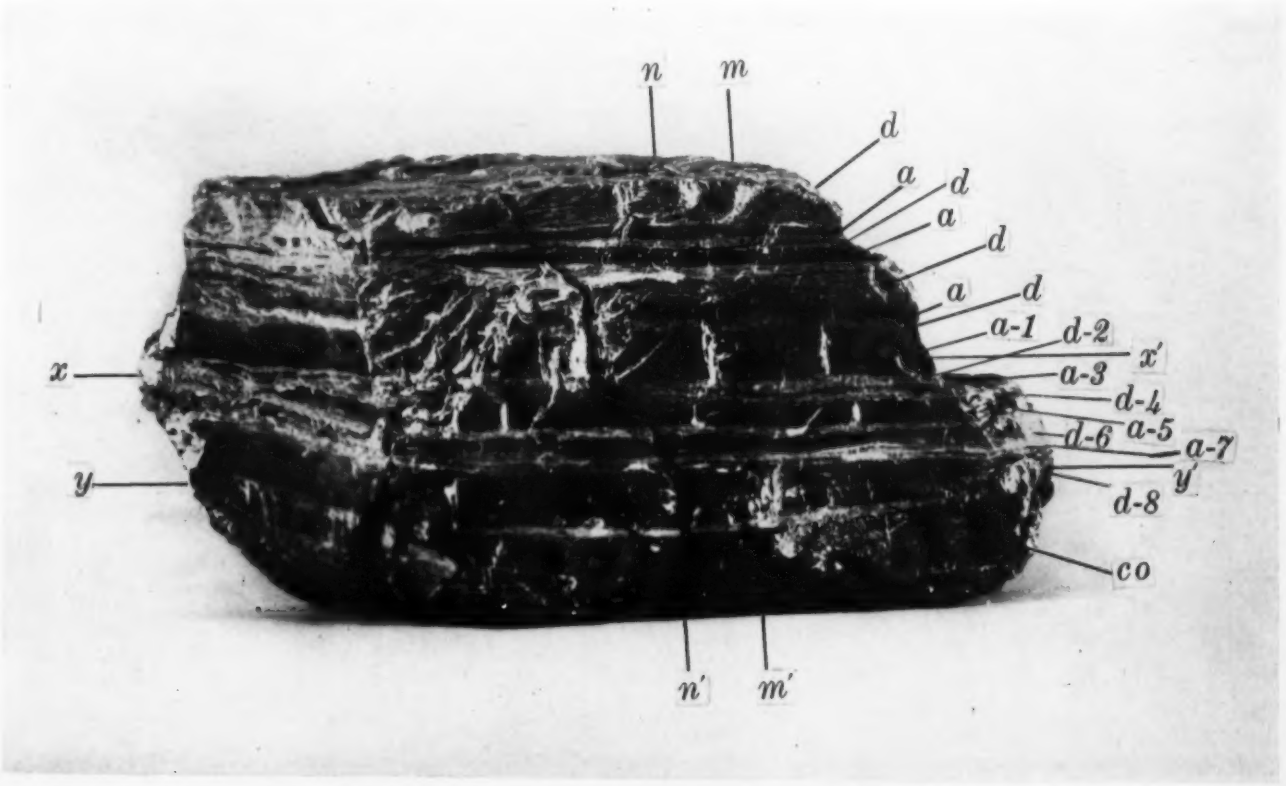


FIG. 1

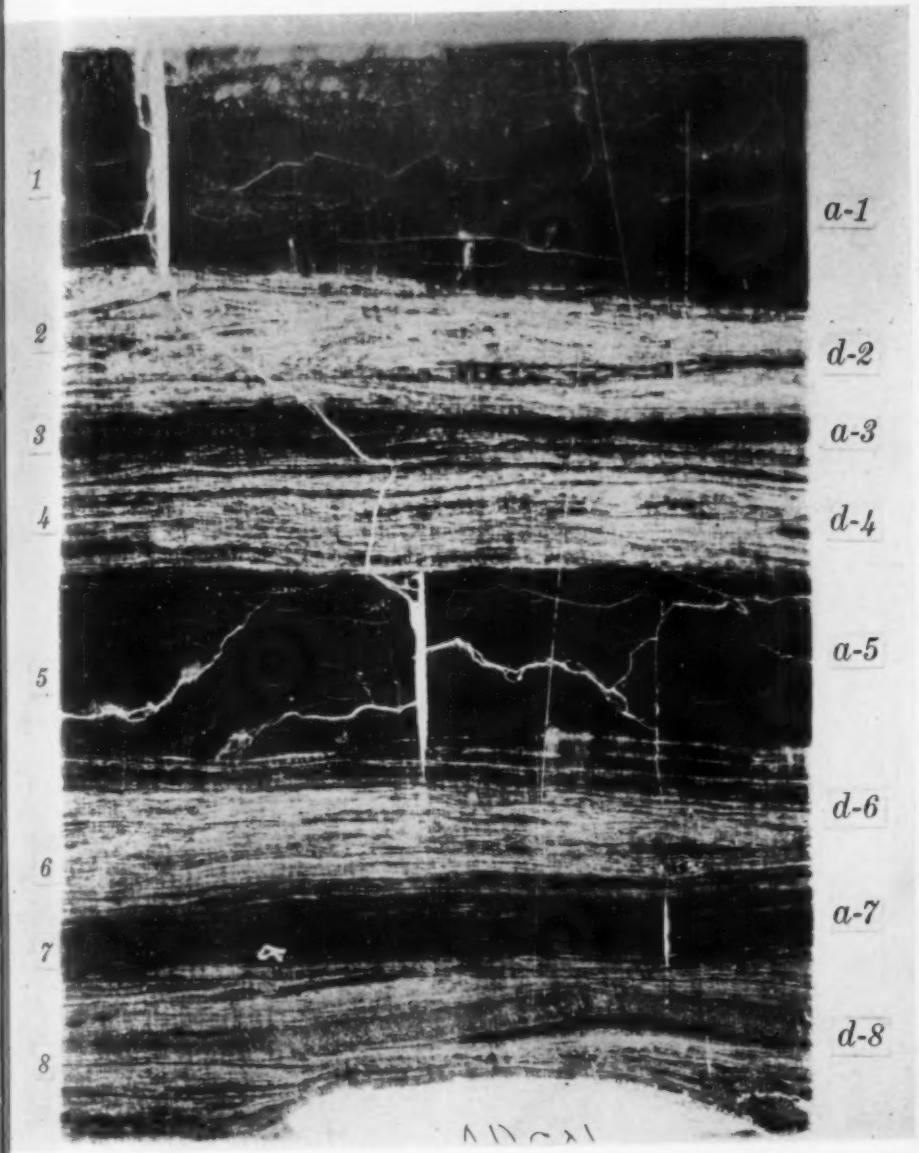
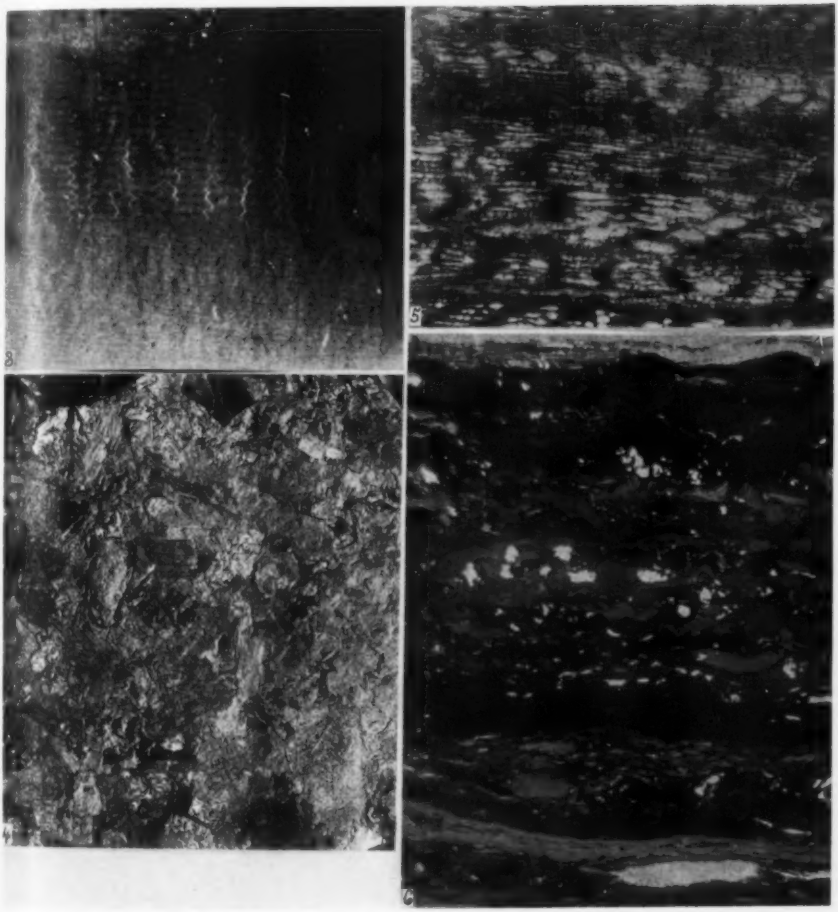
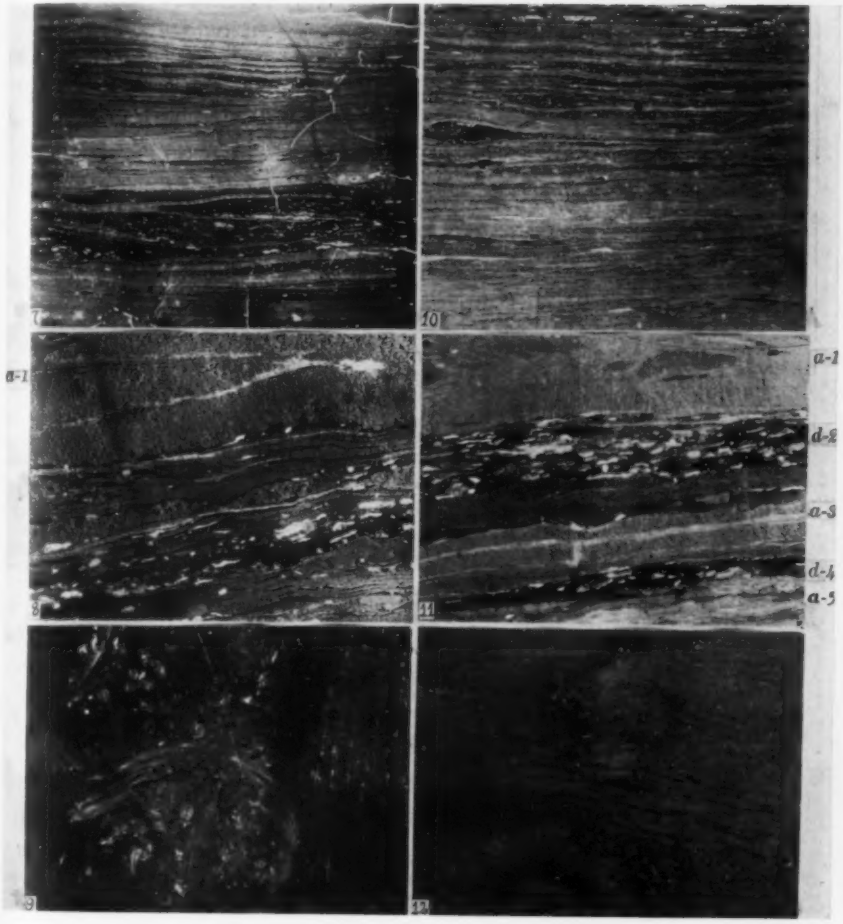


FIG. 2

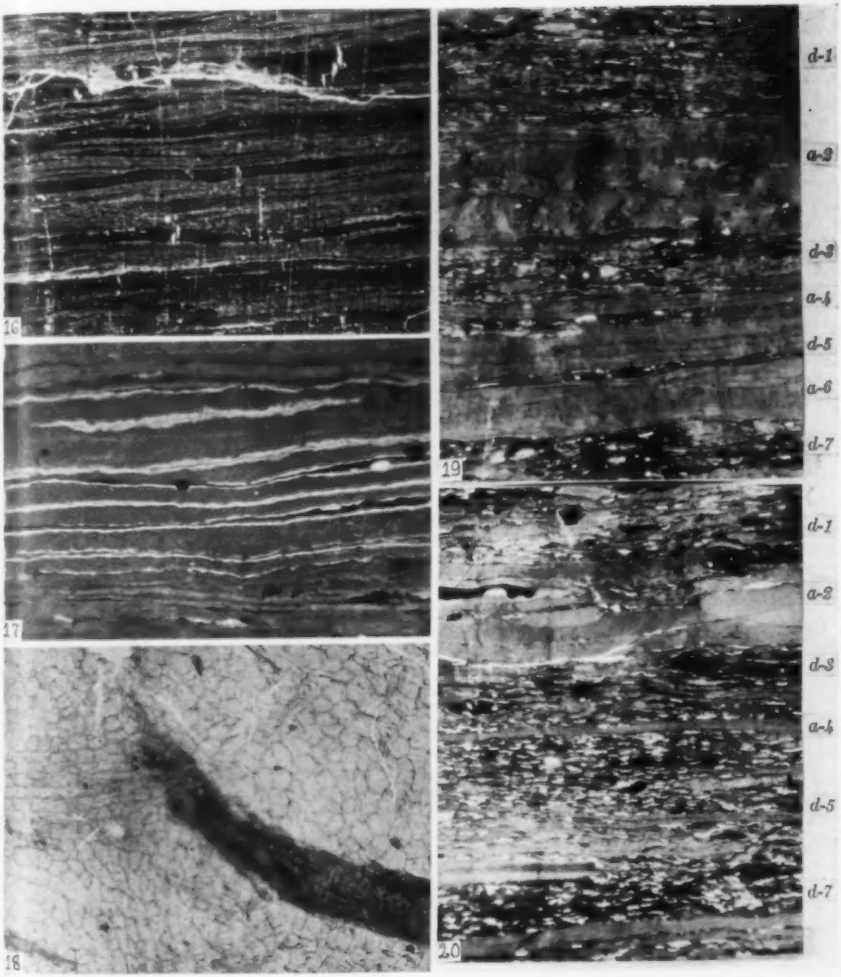


FIGS. 3–6

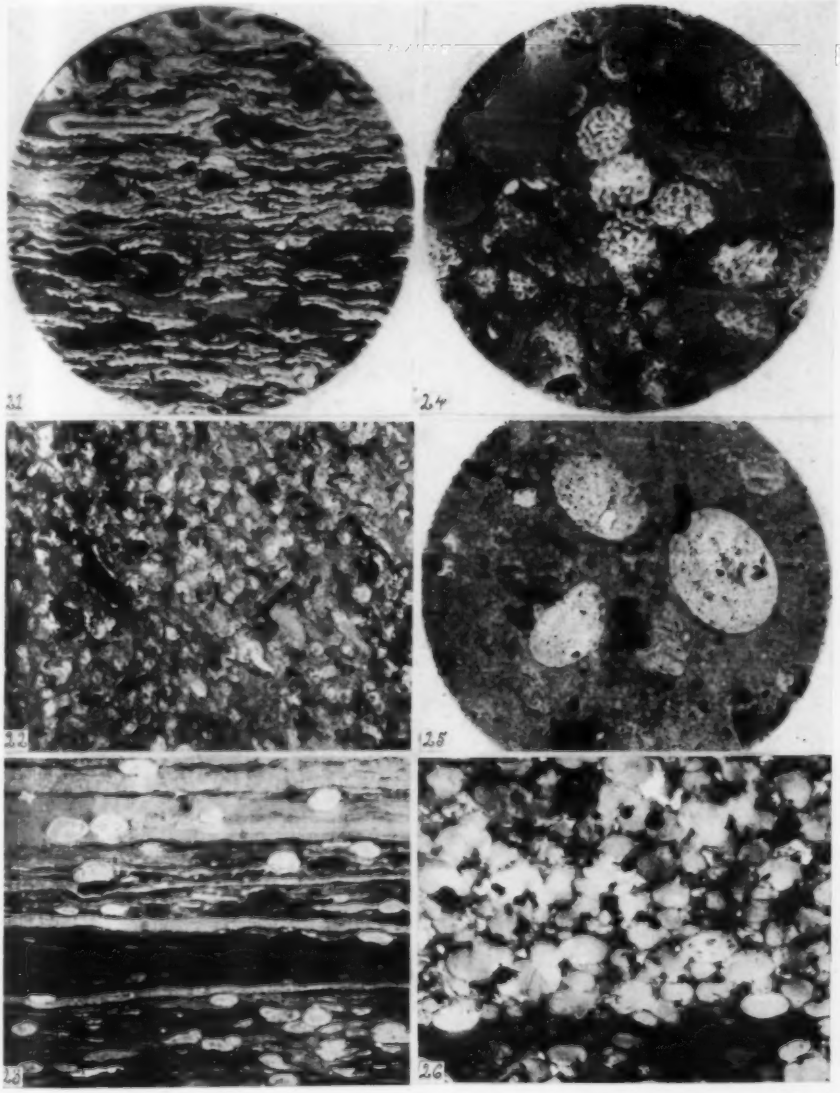


FIGS. 7–12

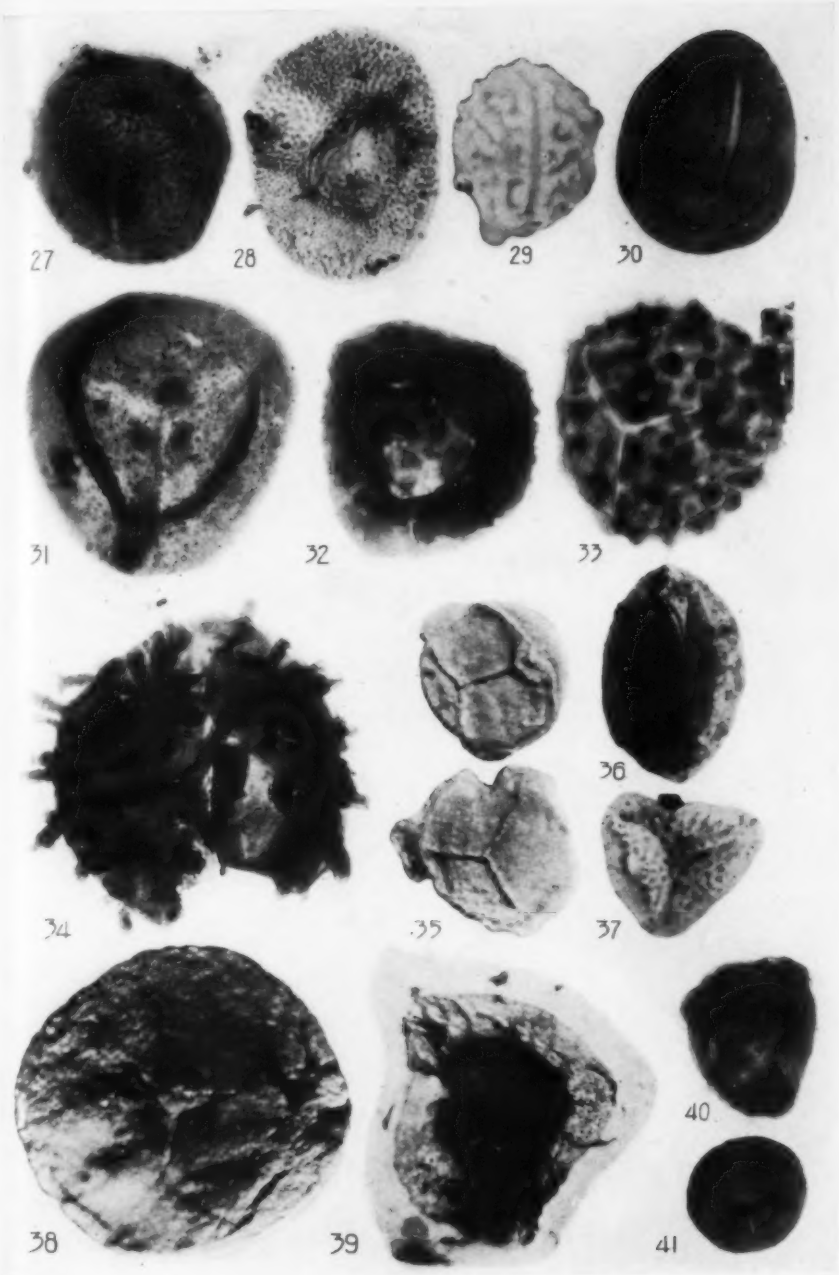
FIGS. 13–15



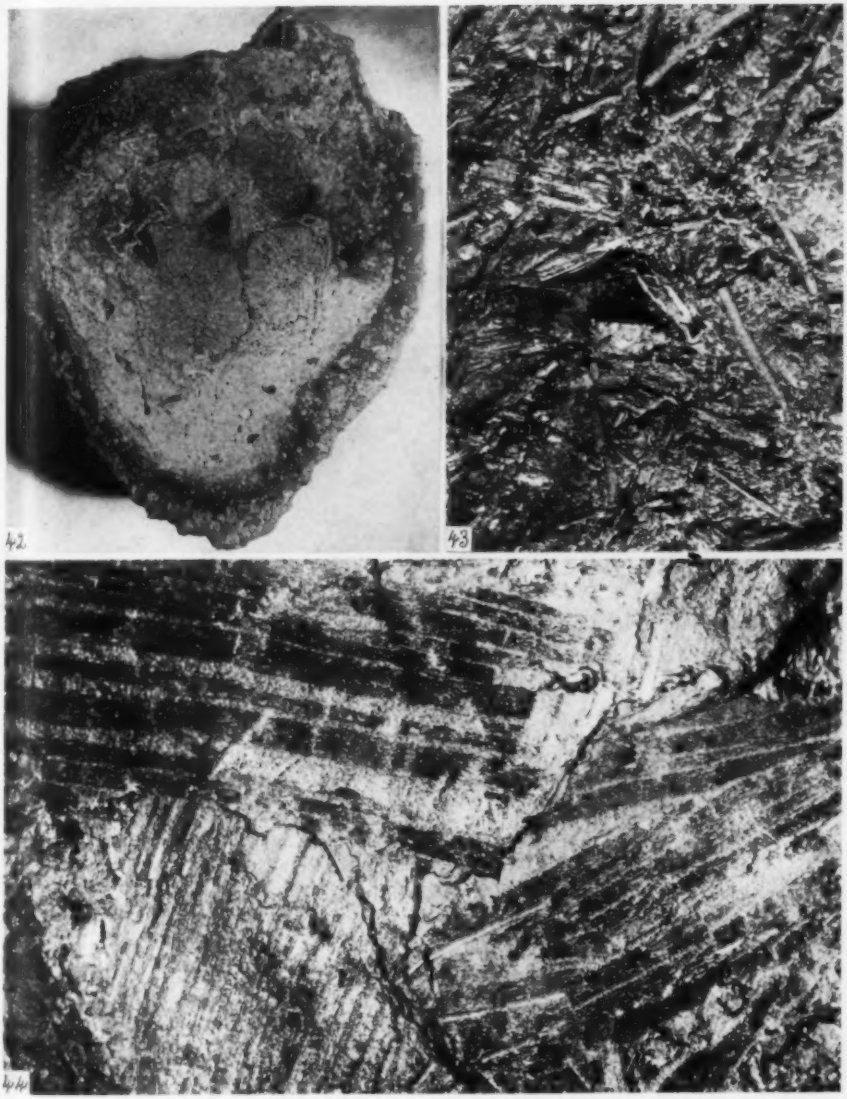
FIGS. 16–20



FIGS. 21–26



FIGS. 27–41



FIGS. 42–44

FIG. 11.—Part of the thin cross-section shown in Figure 5, at a higher magnification. *a*-1 is a thin anthraxylon chip, showing some plant structure; *d*-2, a thin sheet of attritus, containing a large amount of spore matter, some humic matter, and some earthy matter; *a*-3, anthraxylon chips; *d*-4, attritus. × 200.

FIG. 12.—Part of a thin horizontal section of coal from Terre Haute, Indiana. While the cross-sections reveal but very little plant or woody structure, every horizontal section shows a large amount of it, as in this section. × 150.

PLATE VII

FIG. 13.—A close-up view in a typical Wisconsin peat bog.

FIG. 14.—A lump of dried peat from the bog shown in Figure 13, showing thin chips of woody peat or anthraxylon, imbedded in the attritus. Compare this with Figure 4. Natural size.

FIG. 15.—The thin flat pieces of woody peat, picked out of the lump shown in Figure 14. Natural size.

PLATE VIII

FIG. 16.—Part of a thin cross-section of the coal from Ziegler, Illinois, containing a large proportion of cuticular matter. × 10.

FIG. 17.—Part of a thin cross-section of coal similar in appearance and composition as that shown in Figure 16. The heavy white lines running across the photograph represent leaf cuticles imbedded in matter largely derived from leaves. × 200.

FIG. 18.—One of the cuticles separated from the coal and seen flat-wise. × 200.

FIG. 19.—Part of a thin cross-section of a Pittsburgh coal with a number of thin anthraxylon strips. *d*-1, attritus rich in humic matter; *a*-2, thin anthraxylon strips rich in resinous matter; *d*-3, attritus; *a*-4, anthraxylon strips; *d*-5, thin layer of attritus; *a*-6, anthraxylon strip; *d*-7, attritus. Cell structures have been retained in *a*-4 and *a*-6. × 200.

FIG. 20.—Part of a thin cross-section of Pittsburgh coal rich in attritus. *d*-1, attritus composed of humic matter, spore-exines and carbonaceous matter. *a*-2, a thin anthraxylon layer; *d*-3 attritus composed of humic matter, spore-exines, and carbonaceous matter; *a*-4, a very thin strip of anthraxylon; *d*-5 and *d*-7, attritus, composed chiefly of spore-exines, some humic and carbonaceous matters, including thin strips of anthraxylon.

PLATE IX

FIG. 21.—Part of a thin cross-section of the coal from the Pittsburgh seam, at a very high magnification, showing the constituents in detail: spore-exines, in white; humic matter in gray; resinous particles, homogeneous gray, and carbonaceous matter in black. × 1,000.

FIG. 22.—Part of a thin horizontal section through a layer of attritus largely composed of spore matter, some humic matter, and some carbonaceous matter. The small circular to oval spots represent spore-exines; the irregular black spots, carbonaceous matter. × 150.

FIG. 23.—Part of a thin cross-section of coal, showing resinous particles in the anthraxylon and in the attritus.

FIG. 24.—Part of the thin horizontal section of Pittsburgh coal shown in Figure 22, at a very high magnification, showing the spore-exines and other constituents in detail. The spores are characteristic of the Pittsburgh bed. × 1,000.

FIG. 25.—Part of a thin horizontal section of coal from the Pittsburgh seam, at a very high magnification, showing the pollen grain type of spore-exines, imbedded in a matrix consisting of humic, carbonized, mineral, and earthy matter. × 1,000.

FIG. 26.—Part of a thin cross-section of anthraxylous coal from the Vandalia mine, Terre Haute, Indiana, showing a large number of oval resinous particles. The original woody issues have decayed in the part shown. × 200.

PLATE X

Spore-exines isolated from various coals by means of Schulze's reagent and seen flat-wise.

FIG. 27.—Spore-exine found in the coal from Buxton, Iowa. × 1,000.

FIG. 28.—Spore-exine predominant in and characteristic of the coal from Buxton, Iowa. × 1,000.

FIG. 29.—Spore-exine predominant in and characteristic of the Pittsburgh seam.

FIG. 30.—Exine of a pollen grain, common in all coals. × 1,000.

FIG. 31.—Spore-exine characteristic of and predominant in the coal from Shelbyville, Illinois. × 1,000.

FIG. 32.—Spore-exine characteristic of and predominant in the coal from the Sipsey mine, Alabama, Black Creek bed. × 1,000.

FIG. 33.—Spore-exine from bed No. 6, Illinois coal. × 1,000.

FIG. 34.—Spore-exines from an Illinois coal, bed No. 6. × 1,000.

FIG. 35.—Megaspore-exines of a smaller type, found in large numbers in the Shelbyville coal and occasionally in other coals. A megaspore similar to this but with three large air sacks is characteristic of coal from Buxton, Illinois. × 33.

FIG. 36.—Seedlike spore-exine from the Illinois coals, bed No. 6. × 100.

FIG. 37.—Spore-exine found in the coal from bed No. 5, Vandalia, Indiana. × 1,000.

FIG. 38.—Megaspore-exine predominant in the coal from Shelbyville, Illinois, but found occasionally in other coals. × 33.

FIG. 39.—Spore-exines, Spencerite type, common in all coals. × 100.

FIG. 40.—Spore-exine very common in the coal from Sessor, Illinois, but found in other coals from bed No. 6. × 1,000.

FIG. 41.—A spore-exine common in all coals.

PLATE XI

FIG. 42.—Cross-section of a pyritized fossil stem of Medullosa Anglica, showing three steles, surrounded by a common periderm; next to this is the inner cortex forming the outermost zone of tissues. The inner and outer cortexes are pervaded by leaf traces and gum ducts, both recognizable, though not distinctly in the photograph.

FIG. 43.—Part of a cleavage surface of coal, showing a large number of "rodlets" or "needles" imbedded helter-skelter in the attritus. × 10.

FIG. 44.—Part of a horizontal cleavage plane of coal showing a Medullosa type of woody structure, in which "needles" or "rodlets" form part of the tissue. × 3.

A QUANTITATIVE MINERALOGICAL CLASSIFICATION OF IGNEOUS ROCKS—REVISED

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PART III

CLASS 2, ORDER 3

(237) **Calci**granite. No plutonic rock falling near the center point of this family has yet been located.

Quartz-ciminite. Among the extrusives the only rock found in this family is a quartz-bearing ciminite described by Washington.[1] Ciminite, named from its occurrence on Monti Cimini, Italy, was defined[2] as consisting of alkali feldspar, basic plagioclase, augite, and olivine, with accessory magnetite and apatite. From two modal analyses given, it appears that there are quartz-bearing and quartz-free ciminites; consequently the two divisions, quartz-ciminite and ciminite, are here made. A modal analysis of one rock, here called quartz-ciminite, gives orthoclase (Or_6Ab_1) 43.6 per cent, labradorite (Ab_1An_2) 16.1 per cent, quartz 4.6 per cent, apatite 0.7 per cent, augite 22.4 per cent, olivine 11.7 per cent, and magnetite 0.9 per cent. Since this rock contains olivine, it is not representative of the normal extrusives of the family.

(238) **Calci**adamellite. This is a quartz-monzonite whose plagioclase is labradorite. Here fall four specimens from the Elkhorn district, Montana, on the border of the Butte batholith, described by Barrell.[3] The rock, however, is near the border line between Orders 2 and 3. The plagioclase is described as

[1] Henry S. Washington, "Italian Petrological Sketches, II: The Viterbo Region," *Jour. Geol.*, IV (1896), 838.

[2] *Ibid.*, V (1897), 351; "The Roman Comagmatic Region," *Carnegie Publication No. 57* (Washington, 1906), p. 65.

[3] Joseph Barrell, "Microscopical Petrography of the Elkhorn Mining District, Jefferson County, Montana," *U.S. Geol. Surv., Ann. Rept.*, XXII, Part II (1901), p. 538.

"Ab_1An_1 or more basic" by Barrell. On the other hand, Cross, Iddings, Pirsson, and Washington[1] assume, by calculation from the chemical analysis of a specimen from the Butte region, that the plagioclase has Ab_1An_1 centers but more acid borders. The orthoclase in their analysis, however, was calculated as pure potash feldspar, while as a matter of fact it contains considerable soda. Consequently the plagioclase may be, as Barrell says, more basic, and the C.I.P.W. rock would fall in the calciadamellite family with Barrell's rock.

(239) Granogabbro JOHANNSEN.[2] See note under granodiorite (229) and leuco-granogabbro (139).

Rhyobasalt. To have a term analogous to granogabbro, the term rhyobasalt is here used. See note under granodiorite (229).

(2310) Quartz-gabbro.
Quartz-olivine-gabbro.
Quartz-basalt.
Quartz-olivine-basalt.

(2312) **Calci**syenite. No modal analysis of a plutonic rock belonging here has yet been located.

Vulsinite WASHINGTON. Vulsinites are defined by Washington[3] as "effusive rocks occupying an intermediate position between the trachytes and the andesites. They are characterized mineralogically by the presence of alkali feldspar with a large amount of basic plagioclase (labradorite to anorthite) together with augite and diopside. Hornblende and biotite are not abundant in the type specimens, though they may be present in large amounts in other varieties. . . . . Olivine is wanting, or if present is so in only accessory amounts." While the definition would suggest a rock of the latite series, the modal analysis of the Bolsena type[4] shows it to belong to Family 12. The mineral percentages

[1] Cross, Iddings, Pirsson, and Washington, *Quantitative Classification of Igneous Rocks* (Chicago, 1903), p. 227.

[2] Albert Johannsen, "Suggestions for a Quantitative Mineralogical Classification of Igneous Rocks," *Jour. Geol.*, XXV (1917), 89.

[3] Henry S. Washington, "Italian Petrological Sketches, I: The Bolsena Region," *Jour. Geol.*, IV (1896), 553.

[4] *Ibid.*, "The Roman Comagmatic Region," *Carnegie Publication No. 57* (Washington, 1906), p. 65.

are: soda-orthoclase (Or_9Ab_4) 69.5, basic plagioclase (anorthite phenocrysts 6.1, labradorite groundmass 11.9, average Ab_1An_2) 18.0, augite 7.4, biotite 1.0, ores 3.6, apatite 0.4, titanite 0.1.

Ciminite WASHINGTON. The quartz-free ciminite has a mode[1] of soda-orthoclase ($Or_{10}Ab_3$) 50.7 per cent, labradorite (Ab_1An_2) 13.1 per cent, augite 23.2 per cent, olivine 11.2 per cent, magnetite 0.9 per cent, apatite 0.9 per cent. See note under quartz-ciminite (237).

(2313) **Calci**monzonite. The original Monzoni monzonite, according to Brögger, usually contains a basic plagioclase (see note under 2213). In the present classification normal orthoclase-acid-plagioclase rocks are included under the term monzonite and orthoclase-basic-plagioclase (excluding anorthite) rocks under the term calcimonzonite.

Calcilatite. The extrusive equivalent of the preceding.

(2314) **Monzogabbro** (**monzonorite**). The rocks which fall in this family are described in the literature as gabbros, norites, or monzonites. The term syenogabbro, originally proposed[2] for this family, is here withdrawn, and the term monzogabbro substituted for reasons stated under granodiorite (229). Another reason why syenogabbro should not be used for the plutonic rock of this family is that, by analogy, the extrusive should then be called trachy-basalt. But Bořický[3] used the term trachy-basalt for rocks which are now called monchiquites.

Basalatite. Basalatite, as intermediate between basalt and latite, is here suggested. It corresponds in form with its deep-seated equivalent, monzogabbro.

(2315) Gabbro VON BUCH. The term gabbro (*granito di gabbro*) was used by Targioni Tozzetti[4] and other writers for diallage-serpentine and related rocks from Tuscany. Von Buch[5] applied

[1] Henry S. Washington, "The Roman Comagmatic Region," *Carnegie Publication No. 57* (Washington, 1906), p. 32.

[2] Albert Johannsen, *op. cit.*, p. 89.

[3] Emanuel Bořický, "Petrographische Studien an den Basaltgesteinen Böhmens," *Arch. f. d. naturw. Landesdurchf. v. Böhmen*, II (1874), Abt. ii, Th. ii, p. 44.

[4] Targioni Tozzetti, *Relazioni d'alcuni viaggi fatti in diverse parti della Toscana* (Firenze, 1768), II, 432.

[5] Leopold von Buch, "Ueber den Gabbro" (read in Akad. d. Wissens., Berlin, October 12, 1809), *Magazin d. Gesell. naturf. Freunde z. Berlin*, IV (1810), 128–49.

it to rocks consisting of "Saussurit oder Jade und Smaragdit, oder häufiger aus Feldspath und Smaragdit . . . . oder auch seltener aus allen diesen Substanzen vereinigt." His saussurite is altered feldspar, the jade amphibole, and the smaragdite probably green diallage. For a long time the name continued to be applied to plagioclase-diallage rocks, but in recent years the kind of pyroxene has been disregarded, and only the basic character of the plagioclase has been considered essential to the definition. In the present classification, therefore, gabbro is simply a rock consisting essentially of labradorite or bytownite and a biopyribole. Olivine may be an accessory, and magnetite is usually present in variable amounts. The orthoclase-gabbro of Streng[1] and Irving[2] is really diallage-monzonite or monzodiorite.

Hornblende-gabbro.

Olivine-gabbro.

Quartz-gabbro.

Uralite-gabbro, etc.

Norite ESMARK. Esmark[3] applied the name norite to certain Norwegian rocks which belong in part to the rocks now called norites, but in part to the diorites. Scheerer[4] applied it to rocks related to the gabbros and hyperites. Rosenbusch[5] limited it to rocks containing essential hypersthene and plagioclase, and said that unless so limited the term would be meaningless, and later[6] gave the constituents as basic plagioclase and an orthorhombic pyroxene. In this sense it is now generally used.

Hyperite TÖRNEBOHM. These rocks, intermediate between gabbros and norites, and containing both orthorhombic and monoclinic pyroxenes, were originally called hypersthenites

[1] Aug. Streng, "Über die kristallinischen Gesteine von Minnesota in Nordamerika," *Neues Jahrb.* (1877), pp. 113–38.

[2] Roland Duer Irving, "The Copper-bearing Rocks of Lake Superior," *U.S. Geol. Surv., Mono. 5* (1883), pp. 50–52.

[3] Esmark, *Magazin für Naturvidenskaberne*, I, 207.

[4] Th. Scheerer, *Gaea Norvegica*, Heft ii, 313; also "Geognostisch-mineralogische Skizzen gesammelt auf einer Reise an der Süd-Küste Norwegens," *Neues Jahrb.* (1843), p. 668.

[5] H. Rosenbusch, *Mikroskopische Physiographie der massigen Gesteine* (1st ed.; Stuttgart, 1877), p. 477.

[6] *Ibid.* (4th ed., 1907), p. 348.

by Rose.[1] The name was too suggestive of a rock entirely composed of hypersthene; therefore Törnebohm[2] gave to them the name hyperite, although this term had previously been used by Senft[3] for his group composed of eclogites, gabbros, and hypersthenites.

Syn.: Hypersthene-syenit, Hypersthenite ROSE, Hypersthene-gabbro, Augite-norite, etc.

Basalt. The derivation of the term is unknown. It may be derived from the Ethiopian *bsalt*, "cooked," suggesting a baked rock, or from *barzalten*, *barzel*, the Hebrew for "iron." Pliny[4] speaks of "basalten" found in Ethiopia, a rock which "in color and hardness resembles iron, and is used in making statuary." Agricola[5] thought that certain rocks in Saxony were identical with the basalt of the older writers, and applied this term to them, and Werner[6] used it for the same rocks, which he considered sedimentary. Basalt is the extrusive equivalent of gabbro, and in general the term is applied to rocks with basic plagioclase and augite, with or without olivine. Some writers apply the term to plagioclase-augite rocks with olivine, irrespective of the kind of plagioclase, though in general, at the present time, this is not the basis of separation from the andesites. On the basis of the feldspar, therefore, there would be

With acid plagioclase:
- Hornblende-andesite
- Augite-andesite
- Olivine-augite-andesite, etc.

With basic plagioclase:
- Hornblende-basalt
- Basalt (with pyroxene) = Auganite WINCHELL
- Olivine-basalt, etc.

[1] G. Rose, "Über Hypersthenit," *Pogg. Ann.*, XXXIV (1835), 10.

[2] A. E. Törnebohm, "Über die wichtigeren Diabas- u. Gabbro-Gesteine Schwedens," *Neues Jahrb.* (1877), p. 379.

[3] Ferdinand Senft, *Classification und Beschreibung der Felsarten* (Breslau, 1857), p. 59.

[4] C. Plinii Secundi *Naturalis Historiae* xxxvi. cap. vii. Ed. Lugd. Batav. Roterodami, Ao. 1668, p. 645.

[5] Georg Agricola (Georg Bauer), *De re metallica*, 1556.

[6] A. G. Werner, "Bekanntmachung einer . . . . über die Entstehung des Basaltes gemachten Entdeckung . . . . ," *Bergmänn. Journ.*, Pt. II (1788), p. 845.

Winchell[1] suggests the word auganite for olivine-free basalt, and uses basalt for the olivine-bearing variety. The writer prefers basalt and olivine-basalt for these rocks.

According to their textures, basalts have been divided into three groups: basalts proper, anamesite, and dolerite.

Basalt proper. Compact, dense, aphanitic.

Anamesite VON LEONHARD.[2] Megascopically crystalline, but fine-grained. Name derived from *ἀνάμεσος*, "in the middle."

Dolerite HAÜY,[3] from *δολερὸς*, "deceptive." Coarse-grained.

Alboranite BECKE. Becke[4] proposed the term alboranite for certain extrusive rocks from the island of Alboran. They consist of hypersthene and basic plagioclase. The phenocrysts in the rocks described by him are anorthite and the groundmass microlites labradorite. The rocks thus are olivine-free hypersthene-basalts, and, as extrusive representatives of norite, deserve the new name. See note under santorinite (2215).

(2323) Kulaite WASHINGTON. This term was originally applied by Washington[5] to certain extrusive rocks from the volcanoes of Kula, in Lydia, Asia Minor, under the impression that they were hornblende-basalts. Later they were shown by him[6] to be nephelite-bearing and to contain approximately equal amounts of orthoclase and basic plagioclase. No plutonite of this composition has yet been located among modes given in the literature; therefore kulaite is temporarily used as the family name. The term should not be confused with kullait HENNIG.

[1] Alexander N. Winchell, "Rock Classification on Three Co-ordinates," *Jour. Geol.*, XXI (1913), 215; also "Geology of the National Mining District, Nevada," *Mining and Scientific Press*, CV (1912), 657.

[2] Karl Cäsar von Leonhard, *Die Basalt-Gebilde in ihren Beziehungen zu normalen und abnormen Felsmassen* (Stuttgart, 1832), I, 151.

[3] Ascribed to Haüy by Alexandre Brongniart, *Classification et caractères minéralogiques des roches* (Paris, 1827), p. 101.

[4] F. Becke, "Der Hypersthen-Andesit der Insel Alboran," *Tscherm. Min Petr. Mitth.*, XVIII (1899), 553.

[5] Henry S. Washington, "On the Basalts of Kula," *Amer. Jour. Sci.*, XLVII (1894), 115.

[6] *Ibid.*, "The Composition of Kulaite," *Jour. Geol.*, VIII (1900), 618.

Loewinson-Lessing[1] expressed the opinion that kulaite is the extrusive equivalent of heumite, with which the present writer does not agree. Heumite is described by Brögger[2] as a rock essentially of soda-orthoclase or soda-microcline with other feldspars, very small amounts of nephelite and sodalite, and considerable barkevikite and biotite. Furthermore, the leucocratic minerals in heumite form only 53 per cent of the rock, and the subordinate plagioclase is oligoclase-albite, and not basic plagioclase.

(2324) **Nephelite-(leucite-)monzogabbro.** A term suggested here for the nephelite-(leucite-)bearing rocks of the basic plagioclase series, and comparable to the granogabbros among those bearing quartz. Nephelite-syenogabbro, suggested previously,[3] is withdrawn. See notes under (229) and (2314).

Essexite SEARS is quite variable, but probably belongs here or to (2325), or to both, although the original description by Sears[4] does not mention the presence of orthoclase. He says it contains augite, hornblende, biotite, plagioclase, and nephelite with the usual accessories. Washington,[5] describing the same rock, says that it is essentially a basic monzonitic rock in which feldspathoids and both lime-soda and alkali feldspars are present. The feldspar ranges from Ab_1An_1 to Ab_1An_2, and "an alkali-feldspar is not uncommon . . . . often microperthitic." Nephelite is fairly abundant. In another specimen the plagioclase was Ab_1An_3 and only a few grains of alkali-feldspar were seen. Speaking of certain other rocks described as essexites, Washington[6] says that since they contain neither nephelite nor alkali-feldspar, they are not essexites. Many rocks, clearly not essexites, have been described

[1] F. Loewinson-Lessing, "Kritische Beiträge zur Systematik der Eruptivgesteine, V," *Tscherm. Min. Petr. Mitth.*, XXI (1902), 322.

[2] W. C. Brögger, *Die Eruptivgesteine des Kristianiagebietes. III: Das Ganggefolge des Laurdalits* (Kristiania, 1898), pp. 98–113.

[3] Albert Johannsen, "Suggestions for a Quantitative Mineralogical Classification of Igneous Rocks," *Jour. Geol.*, XXV (1917), 89.

[4] John H. Sears, "Elaeolite-Zircon-Syenites and Associated Granitic Rocks in the Vicinity of Salem, Essex County, Massachusetts," *Bull. Essex Inst.*, XXIII (1891), 146.

[5] Henry S. Washington, "The Petrographical Province of Essex County, Massachusetts," *Jour. Geol.*, VII (1899), 53–56.

[6] *Loc. cit.*

under this name. The original rock is apparently of Class 2 (though some recently described essexites are of Class 3), and certainly of Order 3.

(2325) Nephelite-(leucite-)gabbro. Rouvillite O'NEILL belongs here. This is a rock from St. Hillaire, Quebec, described by O'Neill.[1] It may be called a nephelite-gabbro or light-colored theralite. Rosiwal measurements show the rock to consist of nephelite 29.35 per cent, plagioclase ($Ab_{50}An_{50}$ to $Ab_{20}An_{80}$) 55.9 per cent, apatite 1.15 per cent, pyroxene 7.50 per cent, and hornblende 3.64 per cent.

(2327) Heronite COLEMAN. While this is an analcite dike rock, and far from the center point of the family, it is the only rock so far located in this pigeonhole. The name was given by Coleman[2] to a rock from Heron Lake, north of Lake Superior, consisting of much analcite (53 per cent of the leucocratic minerals), orthoclase (28.24 per cent), labradorite (13 per cent), aegirite (4.04 per cent), and limonite and calcite.

(2330) Lugarite TYRRELL[3] is a porphyritic rock, occurring in dikes and as a sill in the Lugar teschenite-picrite complex in the west of Scotland. It consists of analcite (with some nephelite) 50 per cent, labradorite 10 per cent, apatite 2 per cent, titanaugite 20 per cent, barkevikite 15 per cent, and ilmenite 3 per cent. Tyrrell considers the analcite "original, displacing nephelite."

CLASS 2, ORDER 4

(247) **Anorthite-granite.**

(248) **Anorthite-adamellite.**

(249) **Anorthite-granogabbro.**

(2410) Quartz-anorthite-gabbro.

(2412) **Anorthite-syenite.** A syenite whose small percentage of plagioclase is anorthite may be called anorthite-syenite. Here belongs a so-called shonkinite from Elkhorn, Montana, described

[1] J. J. O'Neill, "St. Hilaire (Beloeil) and Rougemont Mountains, Quebec," *Geol. Surv. Canada, Mem. 53* (Ottawa, 1914), p. 35.

[2] A. P. Coleman, "A New Analcite Rock from Lake Superior," *Jour. Geol.*, VII (1899), 435.

[3] G. W. Tyrrell, "The Late Palaeozoic Alkaline Igneous Rocks of the West of Scotland," *Geol. Mag.*, IX (1912), 77–78.

by Barrell.[1] It is hardly typical of the family, however, since it is near the boundary of Class 3. See note under (2112).

(2413) **Anorthite-**monzonite. See note under (2113).

(2414) **Anorthite-monzogabbro.** See notes under (2114) and (2314).

(2415) Anorthite-gabbro. Here belongs an anorthite-augite dike rock from the Carlingford district, Ireland, with the percentages 62 and 38 according to a calculated analysis by Roth.[2] The corresponding extrusive rock, with more than 50 per cent anorthite, 33 per cent augite, and 8 per cent magnetite, was described as anorthite-diabase by Tschermak.[3]

Another rock belonging to this family is kyschtymite MOROZEWICZ,[4] an anorthite-corundum rock, occurring as an intrusive in granite in Kyschtym in the Urals. Still another is allivalite HARKER,[5] occurring on Allival, a mountain on the Isle of Rum and consisting of anorthite and olivine.[6] Finally, there is rougemontite O'NEILL,[7] containing anorthite 52.25 per cent, augite 32.51 per cent, olivine 8.35 per cent, hornblende 0.43 per cent, and iron ore 6.52 per cent.

CLASS 3, ORDER 1

(316) **Mela-orthogranite.** In this family fall two rocks, Prowersose (of the quantitative system of C.I.P.W.), described by Cross,[8] a dike rock from Two Buttes, Colorado, and a similar rock

[1] Joseph Barrell, "Microscopical Petrography of the Elkhorn Mining District, Jefferson County, Montana," *U.S. Geol. Surv., Ann. Rept.*, XXII, Part II (1901), p. 519.

[2] J. Roth, *Gesteinsanalysen*, lvii. The rock was originally calculated by G. Haughton (*Quart. Jour. Geol. Soc.*, XII [1856], 197) as anorthite 85.84 per cent and augite 14.16 per cent, which was shown to be wrong by Roth.

[3] Gustav Tschermak, "Über secundäre Mineralbildungen in den Grünsteingebirge bei Neutitschein," *Sitzungsber. d. Wien Akad. d. Wiss.*, XL (1860), 127.

[4] J. Morozewicz, "Kyschtymit—ein Korund-Anorthitgestein," *Tscherm. Min. Petr. Mith.*, XVIII (1898), 202.

[5] Alfred Harker, "Igneous Rocks from the Ultrabasic Group of the Isle of Rum. Summary of Progress," *Geol. Surv.* (1903), p. 56.

[6] J. W. Judd, "On the Tertiary and Older Peridotites of Scotland," *Quart. Jour. Geol. Soc.*, XLI (1883), 389–90, 395.

[7] J. J. O'Neill, "St. Hilaire (Beloeil) and Rougemont Mountains, Quebec," *Geol. Surv. Canada, Mem. 43* (Ottawa, 1914), p. 77.

[8] Whitman Cross, "Prowersose (Syenitic Lamprophyre) from Two Buttes, Colorado," *Jour. Geol.*, XIV (1906), 165.

from Knox County, Maine, described by Bastin.[1] They are melanocratic orthogranites.

(317) **Mela**-albite-granite. A poor name, which should be replaced owing to the former use of albite-granite for a different kind of rock. See note under (217).

(318) **Mela-albite**-adamellite. See note under (218).

(319) **Mela-albite**-granodiorite. See note under (219).

(3110) **Mela-albite**-tonalite. See note under (2110).

(3111) **Mela-orthosyenite.** See note under (2111).

(3112) **Mela-albite**-syenite. See note under (2112).

(3113) **Mela-albite**-monzonite. See note under (2113).

(3114) **Mela-albite-monzodiorite.** See note under (2114).

(3115) **Mela-albite**-diorite. See note under (2115).

(3116) **Ortho**shonkinite. Weed and Pirsson[2] gave the name shonkinite (from Shonkin, the Indian name for the Highwood Mountains, Montana) to a melanocratic "granular plutonic rock consisting of essential augite and orthoclase. . . . . It may be with or without olivine, and accessory nepheline, sodalite, etcetra, may be present in small quantities." In another place[3] they state that "a triclinic striated feldspar is also present, but in no considerable amount. . . . . It is albite." The amount of albite is not mentioned, but it is included in the estimated amount of alkali-feldspar. Based on the definition, however, no albite is necessary, and by analogy with other rocks (see under (111)) the term ortho-shonkinite may be applied to the rocks as defined with less than 5 per cent albite. Where the albite percentage is greater, the rock falls into Family 17 as albite-shonkinite or shonkinite simply. While the original rock contained traces of feldspathoids, by definition none is necessary, and none is shown in the mode of this rock as given by Washington.[4] It has, however, affinities with the nephelite rocks; consequently, though it may fall on the feldspar base line of the double triangle, it is to be classed with the

[1] Edson S. Bastin, "Some Unusual Rocks from Maine," *Jour. Geol.*, XIV (1906), 173–80.

[2] Walter H. Weed and Louis V. Pirsson, "Highwood Mountains of Montana," *Bull. Geol. Soc. Amer.*, VI (1895), 415–16.

[3] *Ibid.*, p. 412.

[4] Henry S. Washington, "The Foyaite-Ijolite Series of Magnet Cove: A Chemical Study in Differentiation," *Jour. Geol.*, IX (1901), 613.

feldspathoid rocks in Family 16. Furthermore, a modal analysis of another rock[1] shows alkali-feldspar 20 per cent, nephelite 5 per cent, sodalite 1 per cent, apatite 4 per cent, and mafites 70 per cent (10 of which is olivine). The latter rock, consequently, may be called a nephelite-shonkinite of Family 21.

(3117) Shonkinite. This is albite-bearing shonkinite. See note under (3116).

(3121) **Nephelite-**shonkinite. See note under (3116).

(3124) **Mela**litchfieldite. See note under (2124).

(3125) **Mela**mariupolite. See note under (2125).

(3131) Bekinkinite ROSENBUSCH and Missourite WEED and PIRSSON.

The melanocratic nephelite plutonic rock of this family is represented by bekinkinite, named by Rosenbusch[2] from its occurrence on Mount Bekinkina on the peninsula Ambavatoby, as described by Lacroix.[3] While the original rock is said to contain a small amount of anorthoclase, the definition of the type rock of Rosenbusch does not require it. He calls it a plutonic form of nephelite basalt, and says it is related to ijolite as missourite is to fergusite.

Missourite was named by Weed and Pirsson[4] from its occurrence on the Missouri River. It is a melanocratic, feldspar-free leucite rock. It contains 16 per cent leucite, 8 per cent analcite and zeolites, 50 per cent augite, 6 per cent biotite, and 5 per cent iron ore.

Farrisite BRÖGGER[5] is a melanocratic melilite rock of this family.

Mela-nephelite-basalt is the extrusive equivalent of bekinite, **mela-**leucite-basalt of missourite, and **mela-**melilite-

[1] Louis V. Pirsson, "Petrography and Geology of the Igneous Rocks of the Highwood Mountains, Montana," *U.S. Geol. Surv., Bull. 237* (1905), p. 104.

[2] H. Rosenbusch, *Mikroskopische Physiographie der massigen Gesteine* (4th ed.; Stuttgart, 1907), p. 441.

[3] A. Lacroix, "Sur quelques roches ijolithiques du Kilima-Ndjaro," *Bull. Soc. Min. France*, XXIX (1906), 90.

[4] Walter H. Weed and Louis V. Pirsson, "Missourite, a New Leucite Rock from the Highwood Mountains of Montana," *Amer. Jour. Sci.*, II (1896), 323; Louis V. Pirsson, "Petrography and Geology of the Igneous Rocks of the Highwood Mountains, Montana," *U.S. Geol. Surv., Bull. 237* (1905), p. 118.

[5] W. C. Brögger, *Die Eruptivgesteine des Kristianiagebietes. III: Das Ganggefolgschaft des Laurdalits* (Kristiania, 1898), p. 70.

basalt or **mela**-melilitite of farrisite. There are also analcite-basalts, most of which belong in this family, though some fall in Class 2.

CLASS 3, ORDER 2

(327) **Mela**granite. See note under (127).

(328) **Mela**-adamellite. See notes under (127) and (228).

(329) **Mela**granodiorite. See notes under (127) and (229).

(3210) **Mela**tonalite. See notes under (127) and (2210).

(3212) **Mela**syenite. See notes under (127). Some years ago Weed and Pirsson[1] described a rock from the Highwood Mountains as containing about equal amounts of light and dark constituents, and gave to it the name yogoite. Their series of rocks as given was:

All orthoclase, no augite = sanidinite.
Orthoclase exceeds augite = augite-syenite.
Orthoclase equals augite = yogoite.
Augite exceeds orthoclase = shonkinite.
All augite, no orthoclase = pyroxene and peridotite rocks of various types.

Later[2] they withdrew the name yogoite since they found that it fell into Brögger's monzonite group on account of the proportions of orthoclase and plagioclase. The original yogoite, computed in the present system, falls in (2212) and is a normal monzonite, but associated with it, on Yogo Peak, and called shonkinite[3] by Weed and Pirsson, are two other rocks which differ from normal shonkinites in being associated with quartz-bearing instead of with feldspathoid-bearing rocks and in containing andesine instead of albite. They also contain more soda-orthoclase than andesine. These "shonkinites," therefore, may well take upon themselves the discarded name yogoite, since they also occur on Yogo Peak, and fit into the foregoing scheme even better than the original yogoite.

(3213) **Mela**monzonite. See note under (127) and (2213). Here belongs a basic contact monzonite of the Coryell batholith,

[1] W. H. Weed and L. V. Pirsson, "Igneous Rocks of Yogo Peak, Montana," *Amer. Jour. Sci.*, L (1895), 479.

[2] W. H. Weed and L. V. Pirsson, "The Bearpaw Mountains of Montana," *Amer. Jour. Sci.*, I (1896) 357–58.

[3] L. V. Pirsson, "Petrography of the Igneous Rocks of the Little Belt Mountains, Montana," *U.S. Geol. Surv., Ann. Rept.*, XX, Part III (1900), p. 487.

described by Daly,[1] as well as a contact rock against granite described by Miller.[2]

(3214) **Melamonzodiorite.** Based on Daly's[3] average analysis of 161 basalts, as named by the original authors, Leith and Mead[4] computed the mineral composition of the average "basalt" and found that it contained oligoclase 35.4, orthoclase 10.75, augite 36.90, olivine 7.58, magnetite 5.80, ilmenite 0.73, and titanite 2.84. This rock, according to the computed mode, therefore, is not of the gabbro family at all, but of the monzodiorite. Included in Daly's average, of course, are all rocks named "basalts" by the original authors, consequently including many which at the present time would be called andesites.

(3215) **Mela**diorite. Here belong, among dike rocks, many camptonites, kersantites, and spessartites, and some diabases and basalts, though most of the latter rocks belong to Class 2. Among deep-seated rocks there are a few meladiorites.

(3217) **Oligoclase**-shonkinite. **Andesine**-shonkinite. It would be very desirable if there were terms to express the acid-plagioclases exclusive of albite (Ca*N*af, of the present system) and the basic plagioclases exclusive of anorthite (Na*Ca*f). Rosenbusch[5] found the same difficulty when in his description of granite he said: "Oligoklas steht hier und im Folgenden für sauren Plagioklas." A single term would thus cover the rocks of this family. See note under (3116).

CLASS 3, ORDER 3

(337) **Mela-calci**granite. This term is too awkward. The only modal analysis yet found in this family does not lie near the center point.

(339) **Melagranogabbro.** See notes under (127) and (239).

[1] Reginald A. Daly, "Geology of the North American Cordillera at the Forty-ninth Parallel," *Geol. Surv. Canada, Mem. 38*, Part I (1912), p. 361.

[2] William J. Miller, "Geology of the North Creek Quadrangle, Warren County, New York," *N.Y. State Museum, Bull. 170* (1914), p. 37.

[3] Reginald A. Daly, "Average Chemical Compositions of Igneous Rock-Types," *Proc. Amer. Acad. Arts and Sci.*, XLV (1910), 224.

[4] C. K. Leith and W. J. Mead, *Metamorphic Geology* (New York, 1915), p. 74.

[5] H. Rosenbusch, *Elemente der Gesteinslehre* (Stuttgart, 1898), p. 76.

(3310) **Mela**-quartz-gabbro. Too awkward a term. There are three rocks in this family, but all of them are melanocratic hornblende-quartz-gabbros—an "abnormal hornblende-gabbro" in the Moyie sill described by Daly,[1] a quartz-bearing gabbro from the Purcell sill, also described by Daly,[2] and a hornblende-gabbro from Sepänlampi, Hauksuo, Kisko, described by Eskola.[3] The type of the family should be chosen from an augite rock.

(3314) **Melamonzogabbro.** See note under (2314). Here are included two essexites, a hornblende-gabbro, a hornblende-norite, and a so-called gabbro.

(3315) **Melagabbro.** See note under (2315). Many gabbros fall here, also a few norites, and some diabases and basalts (and "dolerites").

Melabasalt. The extrusive equivalent of the above. Arapahite WASHINGTON and LARSEN[4] belongs here.

(3317) **Labradorite-(bytownite-)**shonkinite. See note under (3217).

(3324) **Mela-nephelite-monzogabbro.** See note under (2324).

(3325) Theralite ROSENBUSCH. Theralite, from the Greek θηρᾶν ("eagerly looked for"), was applied by Rosenbusch[5] to plagioclase-nephelite rocks first thought to be represented by certain tephrites and basanites described by Wolff.[6] True theralites, however, were first described by Wolff[7] some years later. Besides the presence of plagioclase and nephelite, these rocks are characterized by much predominating dark constituent; consequently they belong to Class 3. Among the lime-soda feldspars of the rocks

[1] Reginald A. Daly, "Geology of the North American Cordillera at the Forty-ninth Parallel," *Geol. Surv. Canada, Mem. 38*, Part I (1912), p. 234.

[2] *Ibid.*, p. 224.

[3] Pentti Eskola, "On the Petrology of the Orijärvi Region in Southwestern Finland," *Bull. d. l. com. géol. d. Finlande* (Helsingsfors), 1914, p. 71.

[4] Henry S. Washington and E. S. Larsen, "Magnetite Basalt from North Park, Colorado," *Jour. Wash. Acad. Sci.*, III (1913), 452.

[5] H. Rosenbusch, *Mikroskopische Physiographie der massigen Gesteine* (2d ed.; Stuttgart, 1887), p. 248.

[6] J. E. Wolff, "Notes on the Petrography of the Crazy Mts., and Other Localities in Montana Territory," *Northern Transcontinental Survey* (1885), pp. 8–13.

[7] J. E. Wolff, "On the Occurrence of Theralite in Costa Rica, Central America", *Amer. Jour. Sci.*, I (1896), 271.

classed by Rosenbusch[1] as theralites "ist die Labradoritmischung die herrschende, nach auszen hin aufsteigend bis zum Andesin, in den Kernen sinkend bis an die Grenze zum Bytownit." The average feldspar, therefore, is basic plagioclase. Olivine may or may not be present. In the rock from Costa Rica described by Wolff and called the true theralite type by Rosenbusch, who named it, the plagioclase is labradorite. The rock contains, however, a little orthoclase, not necessary in the type.

Kylite TYRRELL,[2] with 31 per cent labradorite, 4 per cent nephelite, 1.3 per cent analcite, 26 per cent titanaugite, 32 per cent olivine, and small amounts of ilmenite, biotite, and apatite, belongs here also. It is a plutonic rock occurring in the Kyle district of Ayrshire, whence its name.

Syn.: Olivine-theralite.

(3330) No plutonic rock has been located in this family, but a rock described as a pikrit-basalt by Quensel[3] from Juan Fernandez occurs among the extrusives. It contains 50 per cent or more of olivine.

CLASS 3, ORDER 4

(3414) **Ricolettaite.** The only rock located here is a dark calcic gabbro from Traversellitthal, north cliff of Ricoletta, Monzoni. It consists of orthoclase 5 to 7 per cent, anorthite 35 to 40 per cent, pyroxene 40 per cent, and a little biotite, olivine, and magnetite. It was described by Doelter[4] and deserves a new name.

(3415) Yamaskite YOUNG. This anorthite-augite rock from Mount Yamaska, Quebec, was described by Young.[5] A similar rock, but carrying olivine, was described by O'Neill.[6]

Olivine-yamaskite.

[1] H. Rosenbusch, *op. cit.* (4th ed., 1907), p. 413.

[2] G. W. Tyrrell, "The Late Palaeozoic Alkaline Igneous Rocks of the West of Scotland," *Geol. Mag.*, IX (1912), 121.

[3] P. D. Quensel, "Der Geologie der Juan Fernandezinseln," *Bull. Geol. Inst. Upsala*, XI (1912), 265.

[4] C. Doelter, "Chemische Zuzammensetzung und Genesis der Monzonitgesteine," *Tscherm. Min. Petr. Mitth.*, XXI (1902), 102.

[5] G. A. Young, "Geology and Petrography of Mount Yamaska, Quebec," *Geol. Surv. Canada, Ann. Rept.*, XVI, Part H (1906), p. 16.

[6] J. J. O'Neill, "St. Hilaire (Beloeil) and Rougemont Mountains, Quebec," *Geol. Surv. Canada, Mem. 43* (Ottawa, 1914), p. 66.

(3430) Several leucitites, so called, fall here, although they are not true leucitites on account of their feldspar content. No plutonic rocks have been located.

CLASS 4, ORDERS 1 TO 3

No attempt is made in this paper to separate the orders of Class 4, since too few modes have been found in the literature to warrant the separation, and measurements by the author, so far, have been chiefly on the rocks of the first three classes. It is hoped shortly to give the modes of some of the classic types of Class 4.

Family 1.—Dunite VON HOCHSTETTER. This rock, named by von Hochstetter[1] from the Dun Mountains, New Zealand, consists of olivine with accessory chromite. The amount of chromite varies greatly. Vogt[2] says that the normal rocks carry from 2 to 5 per cent. They would thus belong to Order 1. Dunites with between 5 and 95 per cent chromite he calls chromite-dunites. With over 95 per cent chromite the rocks may be classed as chromite ores of Order 4. They are represented by the plagioclase-free varieties of Sjögren's[3] Kromit-Olivinit. In other cases the ore is magnetite, as in the magnetite-olivinite series of Sjögren, which includes plagioclase-bearing and plagioclase-free olivine-magnetite rocks. Perhaps good subdivisions would be:

Order 1. Dunite. Olivine between 100 and 95 per cent.

Order 2. Chromite-dunite and magnetite-dunite. Olivine between 95 and 50 per cent.

Order 3. **Olivine-chromitite** and **olivine-magnetitite.** Olivine between 50 and 5 per cent.

Order 4. **Chromitite** and **magnetitite.** Olivine less than 5 per cent.

Families 2 and 5.—These are the families of the mica-(amphibole-)olivine rocks. Among them are mica-peridotite and

[1] Ferdinand von Hochstetter, "Dunit, körniger Olivinfels vom Dun Mountain bei Nelson, New-Seeland," *Zeitschr. d. d. geol. Gesell.*, XVI (1864), 341.

[2] J. H. L. Vogt, "Beiträge zur genetischen Classification der durch magmatische Differentiationsprocesse und der durch Pneumatolyse entstandenen Erzvorkommen," *Zeitschr. f. prak. Geol.* (1894), p. 391.

[3] A. Sjögren, "Om förekomsten af Tabergs jernmalmsfyndighet i Småland," *Geol. Fören. i Stockh. Förhandl.*, III (1876), 58.

amphibole-peridotite. Mica-peridotite was named by Diller[1] from an occurrence in Kentucky. In the type rock the olivine and its alteration products form over 80 per cent, the ores, magnetite, and ilmenite together 4.2 per cent, while biotite, garnet, etc., are accessory. The rock number is (412).

Amphibole-peridotite was first described as amphibole-gabbro by Howitt.[2] Later Rosenbusch[3] compared the same rock with the Schreisheim dike, and still later Verbeek[4] called it amphibole-peridotite. Hornblende-peridotite is the usual variety. Rocks of this class have been called hornblende-picrites by Bonney[5] and hudsonites by Cohen,[6] but since picrite was originally used for an olivine-augite rock and hudsonite for a variety of diallage, Williams[7] proposed for them the name cortlandtite.

A rock whose present mode places it in Family 5 is scyelite JUDD.[8] It consists of hornblende 58.5 per cent, serpentine after olivine 22 per cent, mica 18.5 per cent, and magnetite 1 per cent. Judd says that the hornblende is probably secondary after augite; therefore it possibly should be placed in Family 11.

Families 3, 6, and 10.—In these pigeonholes fall valbellite SCHÄFER[9] and some of the olivinites of SJÖGREN[10] and

[1] J. S. Diller, "Mica-Peridotite from Kentucky," *Amer. Jour. Sci.*, XLIV (1892), 289; also "Peridotite of Elliott County, Kentucky," *U.S. Geol. Surv., Bull. 38* (1887), p. 11.

[2] A. W. Howitt, "The Diorites and Granites of Swift's Creek and Their Contact Zones, with Notes on the Auriferous Deposits," *Proc. Roy. Soc. Victoria*, 1879.

[3] H. Rosenbusch, review of preceding article, *Neues Jahrb.*, I (1881), 221.

[4] R. D. M. Verbeek, *Topographische en geologische beschrijving van een gedeelte van Sumatra's Westkust* (Batavia, 1883), p. 304; also "Description géologique de l'Iel d'Ambon," *Jaarboek van het Mijnwegen in Nederl. Oost-Indie*, XXXIV (1905).

[5] T. G. Bonney, "On a Boulder of Hornblende-Picrite Near Pen-y-Carnisiog. Anglesey," *Quart. Jour. Geol. Soc.*, XXXVII (1881), 137.

[6] E. Cohen, "Berichtigung bezüglich des 'Olivin-Diallag-Gesteins' von Schriesheim im Odenwald," *Neues Jahrb.*, I (1885), 242.

[7] G. H. Williams, "The Peridotites of the 'Cortlandt Series' on the Hudson River Near Peekskill, New York," *Amer. Jour. Sci.*, XXXI (1886), p. 30, note.

[8] John W. Judd, "On the Tertiary and Older Peridotites of Scotland," *Quart. Jour. Geol. Soc.*, XLI (1885), 401–7.

[9] Raimund William Schäfer, "Der basische Gesteinszug von Ivrea im Gebiet des Mastallone-Thalles," *Tscherm. Min. Petr. Mitth.*, XVII (1897), 512–14.

[10] A. Sjögren, "Om förekomsten af Tabergs jernmalms fyndighet i Småland," *Fören. i Stockh. Förhandl.*, III (1876), 58.

EICHSTÄDT.[1] Valbellite consists of bronzite, olivine, and brown hornblende in variable amounts, with accessory magnetite, green spinel, and pyrrhotite. The magnetite may be very abundant. Olivinite covers a group of rocks of varying composition. Essentially they contain olivine with augite and hornblende. Anorthite may be present in some occurrences, but in general it is rare. Another rock belonging here is Saitzew's[2] hornblende-diallage-peridotite from the Koswinski-Kamenj, in the Urals, later described by Duparc and Pearce[3] under the name koswite. This rock consists of much diopside, less olivine and less hornblende in a cement of magnetite, giving a sideronitic texture. Chrome spinel is also present. The main characteristic is the texture, which, the authors say, passes to that of ordinary peridotite by a decrease in the amount of magnetite. The sideronitic texture is not confined to these dikes, but also occurs in other magnetite-rich peridotites.

Families 4 and 11.—This group includes the olivine-pyroxene (both orthorhombic and monoclinic) rocks. Among them are lherzolite DE LAMÉTHERIE,[4] named from the original locality of Lherz, in the Pyrenees, and consisting of olivine, enstatite, and diopside, with accessory picotite. In other localities the pyroxene is diopside and bronzite, and chromite may be present in small amounts.

Diallage-peridotite KLOOS[5] consists of diallage, olivine, and some chromite.

Wehrlite is a name given by von Kobell,[6] in 1834, to a rock from Wehrle in Hungary, under the impression that it was a mineral.

[1] Fr. Eichstädt, "Pyroxen och amfibolförande bergarter från mellersta och östra Småland," *Bihang till Kongl. Svenska Vetenskaps-Akademiens Handlingar*, XI, No. 14 (1887), pp. 95, 123.

[2] A. Saitzew, "Geologische Untersuchungen im Nikolai-Pawdinschen Kreise und Umgebung, im Gebiete des Central-Ural und dessen östlichen Abhang," *Mem. Com. Geol.*, XIII, No. 1 (1892), p. 91.

[3] L. Duparc and F. Pearce, "Sur la koswite, une novelle pyroxénite de l'Oural," *Comptes Rendus*, CXXXII (1901), 892–94.

[4] De Lamétherie, *Théorie de la terre*, II, 281; also *Leçons minéralogique*, II, 206.

[5] J. H. Kloos, "Über Uralit und die strukturellen Verschiedenheiten der Hornblende in einigen Gesteinen des Schwarz- und Odenwaldes," *58 Vers. deutsch. Naturf. u. Arzte* (Strassburg, 1885); also "Studien im Granitgebiet des südl. Schwarzwaldes," *Neues Jahrb.*, III (1884), 146.

[6] Franz von Kobell, *Geschichte der Mineralogie* (München, 1864), p. 660.

The name is now generally applied to peridotites with olivine and much diallage or augite, although the type rock actually contains considerable hornblende and belongs to Family 3, 6, or 10.

Harzburgite ROSENBUSCH[1] and saxonite WADSWORTH[2] were applied to peridotites composed of olivine and a monoclinic pyroxene. Vogt,[3] following Brögger, uses saxonite for the iron-poor olivine-enstatite rocks and harzburgite for the iron-rich members. A saxonite from Minnesota, described by Hall,[4] consists of enstatite 60 per cent, olivine 35 per cent, and ores 5 per cent, consequently belongs to (4211).

Families 7 and 9.—These are the families of the olivine-free amphibole-(or biotite-)pyroxene rocks. Here belong Cromaltite SHAND,[5] consisting of aegirite-augite 51.9 per cent, melanite 15.6 per cent, biotite, apatite, and ores. Its number is (429). A hornblende-hypersthenite, named bahiaite by Washington,[6] with the percentages hypersthene 46, augite 5, hornblende 40.7, and ores 8.3 (rock number 429), also belongs here. Washington says olivine is negligible in bahiaite, but one such rock described by him[7] contains 7.5 per cent, which places it in Family 10.

Family 8.—This is the family of the amphibolites and hornblendites. Among these is a hornblendite from Brazil, described by Washington.[8] It consists of hornblende 91.6 per cent, olivine 3.6 per cent, and magnetite 5.1 per cent.

[1] H. Rosenbusch, *Mikroskopische Physiographie der massigen Gesteine* (2d ed.; Stuttgart, 1887), p. 269.

[2] M. E. Wadsworth, *Lithological Studies* (Cambridge, Mass., 1884).

[3] J. H. L. Vogt, "Beiträge zur genetischen Classification der durch magmatische Differentiationsprocesse und der durch Pneumatolyse entstandenen Erzvorkommen," *Zeitschr. f. prak. Geol.* (1894), p. 384, note.

[4] C. W. Hall, "The Gneisses, Gabbro-Schists, and Associated Rocks of Southwestern Minnesota," *U.S. Geol. Surv., Bull. 157* (1899), p. 111.

[5] S. J. Shand, "On Borolanite and Its Associates in Assynt," *Trans. Edinburgh eol. Soc.*, IX (1910), 394.

[6] Henry S. Washington, "The Charnockite Series of Igneous Rocks," *Amer. Jour. Sci.*, XLI (1916), 331–32.

[7] *Ibid.*, "An Occurrence of Pyroxenite and Hornblendite in Bahia, Brazil," *Amer. Jour. Sci.*, XXXVIII (1914), 86.

[8] *Ibid.*, p. 82.

Another rock belonging here is the biotite-pyroxenite from New Zealand described by Hutton.[1] It consists of biotite and hornblende in about equal proportions.

Family 12.—Finally, in Family 12, belong the pure pyroxene rocks, such as diallagite, bronzitite, hypersthenite (together called pyroxenolites by Lacroix).[2] Websterite WILLIAMS,[3] named from Webster, North Carolina, contains both orthorhombic and monoclinic pyroxenes with accessory iron ores.

Ilmenite-enstatitite VOGT[4] contains as much as 60 per cent ilmenite; consequently it ranges from Order 2 to 3. A magnetite-pyroxenite described by Jennings[5] and Bastin[6] also belongs to Order 3. It contains 67.25 per cent magnetite, 8.30 per cent ilmenite, 16.89 per cent diopside or augite, 6.70 per cent spinel, and .18 per cent apatite.

APPENDIX

This appendix might be introduced by the Spanish proverb: "El sabio muda consejo, el necio no," were there no danger of some critic replying with: "Prudentis est mutare consilium; stultus sicut luna mutator."

In the first instalment of this paper (p. 38), the writer spoke of a contemplated change by which seventy-two families were to be omitted, but letters sent to a considerable number of petrographers found no uniformity of opinion. Some were in favor

[1] F. W. Hutton, "On a Hornblende-Biotite Rock from Dusky Sound, New Zealand," *Quart. Jour. Geol. Soc.*, XLIV (1888), 745–46; also "The Eruptive Rocks of New Zealand," *Jour. and Proc. Roy. Soc. New South Wales*, XXIII (1889), Part I, p. 154.

[2] A. Lacroix, "Sur les roches basiques constituant des filons minces dans la lherzolite des Pyrénées," *Comptes Rendus*, CXX (1895), 752–55.

[3] George H. Williams "The Non-feldspathic Intrusive Rocks of Maryland and the Course of Their Alteration," *Amer. Geol.*, VI (1890), 40–41.

[4] J. H. L. Vogt, "Bildung von Erzlagerstätten durch Differentiationsprocesse in basischen Eruptivmagmata," *Zeitschr. f. prak. Geol.* (1893), p. 8.

[5] E. P. Jennings, "A Titaniferous Iron-Ore Deposit in Boulder County, Colorado," *Trans. Amer. Inst. Min. Eng.*, XLIV (1913), 14–25.

[6] Edson S. Bastin, "Economic Geology of Gilpin County and Adjacent Parts of Clear Creek and Boulder County, Colorado," *U.S. Geol. Surv., Prof. Paper 94* (1917), p. 47.

of dropping all the rocks of the monzonitic series, others of retaining all; some favored dropping the quartz-monzonites but not the monzonites, others dropping the monzonites but not the quartz-monzonites. During the past year, while the foregoing paper was awaiting its turn for publication and while going through the press, the writer collected and determined many more modes and found that the monzonitic group is unnecessary except possibly in the granite-granodiorite and syenite-diorite series. Now apparently the only monzonites which anyone desires to retain are those of these two groups. Consequently the writer believes the following changes will satisfy all sides.

All classes and orders are to be subdivided as stated on pages 38 to 40. Families are to be divided and numbered hereafter as shown in Figure 7 instead of as in Figure 4, the divisions

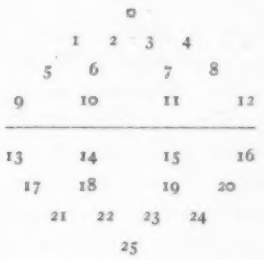

FIG. 7.—The new subdivisions for families

being at 0–5–50–95–100. In the case of the quartz-monzonites-granodiorites, and syenites-monzonites-monzodiorites (Families 7–8–9, and 12–13–14, Fig. 4), subdivisions *may* be introduced if desired with the 0–5–35–65–95–100 per cent limits as before. In such cases they will be numbered, to conform with the new family numbers, 5, 6′, 6′–7′, 7′, 8, 9, 10′, 10′–11′, 11′, 12. Therefore, for example:

226 is normal granite with the Kf-Plag ratio between 95–5 and 50–50.

2210 is normal syenite with the same Kf-Plag ratios.

227 is granodiorite as originally intended by Lindgren (p. 168 above) with the Kf-Plag ratio 50–50 to 5–95. (Family 237 is granogabbro.)

2211 is normal syenodiorite (2311 syenogabbro) with Kf-Plag ratio like the preceding.

For those who wish to use the monzonitic subfamilies:

226′ is more limited granite with the Kf-Plag ratio between 95–5 and 65–35. It may be called monzogranite.

2210′ is limited syenite with the same Kf-Plag ratios. It may be called monzosyenite.

226′–7′ is quartz-monzonite or adamellite, Kf-Plag ratios 65–35 to 35–65.

2210′–2211′ is monzonite, with same ratios as preceding.

227′ is limited granodiorite with Kf-Plag ratios between 35–65 and 5–95. Better called monzotonalite, leaving granodiorite for 227.

2211′ is monzodiorite, same ratios as preceding.

Thus petrographers who wish to use quartz-monzonite and monzonite have subfamilies at their disposal and these subfamilies may be carried through the whole system if desired. Normally only the families would be used.

So far as names are concerned, they remain as given in the preceding article except that Families 3, 8, 13, 18, 23, and 28 drop out entirely and the adjacent families (and their names) extend to the center line.

In Class 4 the subdivisions are to be made on the same divisions, therefore the left face of Figure 5 should be divided as the upper half of Figure 7 and the positions computed in the same manner as the families in the other classes.

In Part I, therefore, the following changes are to be made in the rules on pages 43 and 44.

Page 43, 3 lines from bottom, *omit* five.

Page 44, lines 7–8, *for* 0–5–35–65–95–100 *read* 0–5–50–95–100.

Page 44, lines 12–14, *for* the mineral of one corner, etc., to end of sentence, *read* olivine to the sum of the biopyriboles, and of biotite plus amphibole to pyroxene.

Another correction that should be made is on page 42, where zinnwaldite is to be taken away from the auxiliary constituents and added to the dark micas under mafites.

The principal advantage of the system as it now stands is in the rapidity with which a rock may be classified. It is much easier to determine whether the potash feldspar is greater or less in amount than the plagioclase than it is to estimate whether it falls between the 5–35–65–95 limits.

GEOLOGICAL SETTING OF NEW MEXICO

CHARLES KEYES
Des Moines, Iowa

The unique distinction which New Mexico holds in American geology is that it is the meeting-point of four major and diverse geographic provinces. Together these four provinces embraces nine-tenths of the North American continent. Effects of general land depletion under widely different climatic conditions are thus rarely so strongly contrasted.

Situated well within the boundaries of the vast southwestern desert, the operations of the epicene geologic processes are rendered the more conspicuous because of the fact that they are so very different from those of the pluvial eastern parts of the country with which most of us are most familiar.

New Mexico is distinctly a mountainous country. Its orogeny, however, is chiefly erosional rather than tectonic. Relief of the area is characteristically that of a land of little rain. Facial expression of the region is clearly not stream-corraded but wind-abraded. Owing to the fact that the wind sweeps up its chips as fast as it cuts them the magnitude of eolic erosion is at first difficult to measure with any great degree of satisfaction. Except under especially favorable conditions definite figures cannot always be given. Only when a desert chances to have, somewhere within its boundaries, remnants of old peneplains highly uplifted may the extent of regional depletion be closely estimated. As do moist lands under the influences of stream activities, so arid regions soon develop strong contrasts of surface relief under wind scour. Belts of weak rocks are soonest worn down, leaving the hard rock masses protruding as mountains

In a region of uniform flat-lying strata the relief contrasts are not always marked. When, however, there are rock beds of great thickness, alternating hard and soft members, with close-patterned mountain structures as in the arid lands of western United States,

differential relief effects attain maximum extremes. In this tract it is that the seeming youthfulness of the lofty desert mountains is at once impressed with amazing vividness upon the mind of the observer fresh from his pluvial homeland.

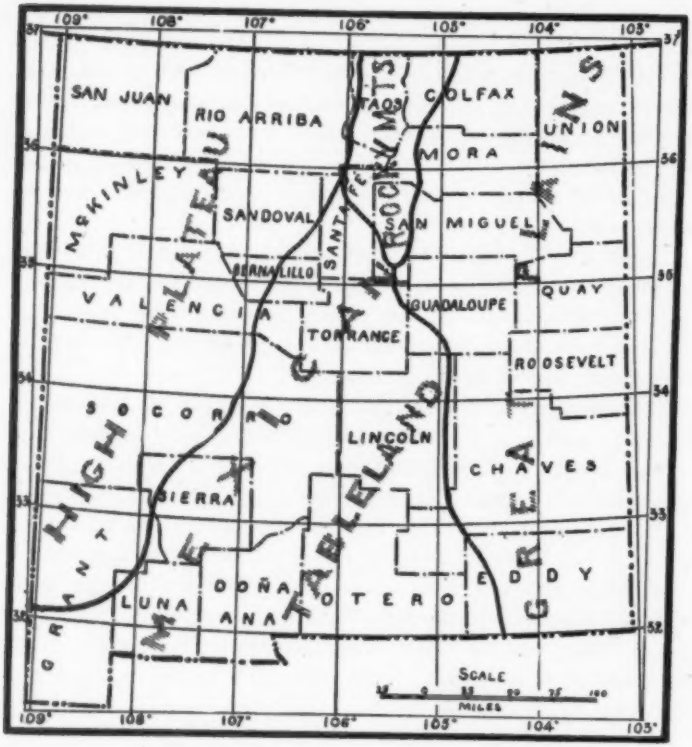

FIG. 1.—Physiographic regions of New Mexico

Once clearly discriminated, wind-graved relief expression is seldom mistaken for any other kind. Its individuality is very strong. Wind-beveled surfaces are smoother than water-formed plains possibly can be. The rock floors which characterize so many desert plains are phenomena as novel as they are unexpected.

Desert ranges rising abruptly out of the plains about impart characteristic form to the enisled landscape. The girdled mountain attests the vigor of natural sand-blast action; and its maximum effectiveness is at the plains line. Plateau plains of the desert manifestly represent former levels of the general plains surface. The notable absence of foothills around the mountain bases appears to be an idiosyncrasy of arid lands.

Arid planatation takes place uphill as well as down; antigravitational gradation is unknown where streams erode. High gradients of the intermontane plains and strong pitch of valley

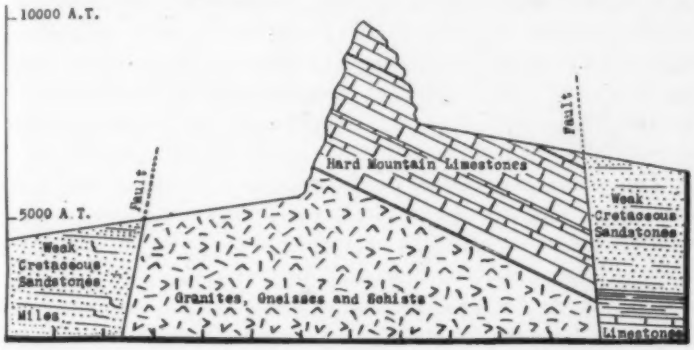

FIG. 2.—Sierra de los Caballos: origin of enisled relief

axes which are displayed on every hand are not possible in regions where water action is directly the reverse of plains forming. Of minor features attributable to wind abrasion in the lands of little rain, there are a multitude that have been ascribed to normal water corrasion but that are now known never to have been touched by stream. Upon all of these the wind marks when once pointed out are unmistakable.

It so happens that the broad arid tract of southwestern United States has within its borders abundant traces of former base-level plains, one of which peneplains is now raised more than two miles above sea-level. The attainment of its present position is regarded as having taken place in late Tertiary times. This great peneplain no doubt once extended over all of this desert region, at a level

somewhat above the tops of the present mountains. Inasmuch as desert conditions began to set in about the same time, there is every reason to believe that the magnitude of the general land depletion is represented by the difference between this old peneplain level and the present plains level—an interval of between 5,000 and 6,000 feet—or something over one mile of thickness, over an area equal to nearly one-quarter of that of the entire United States.

There are many considerations supporting the assumption that this area was before recent uplift a vast plain rather than a mountainous tract when arid climate was inaugurated. Inappreciable aid from stream corrasion in this prodigious regional depletion is indicated by the very fact of the prevalence of aridity itself. This region is one of the best extant, demonstrating beyond peradventure the almost boundless potency of the wind as an epicene power in re-forming the face of earth.

For general purposes of earth study no part of our land is so favored as New Mexico. More diverse phenomena are crowded together in limited space than perhaps anywhere else on our globe. Every known category of geologic process appears to be represented. Every known cause of geographic product seems to have been in operation. In great variety and with diagrammatic distinctness of textbook illustration are the larger rock structures displayed. Everything, too, is on such a gigantic scale. Such phenomena as dikes and faults have to be viewed from afar, from distances of miles, in order to get proper perspective of their relations. Orographic features, which are usually assumed to be structural, are found to be mainly erosional.

From the lofty cornice of the Sandias a landscape prospect spreads out a distance equal to that from New York to Chicago. Billows of mountain ridge take on an aspect of choppy sea as viewed from the deck of an ocean liner. The silver thread of the Rio Grande glints in the light of the desert sun for 400 miles until finally lost on the verge of the world—so clear is the dry, thin air of the desert.

The crystalline framework of the region is both varied and substantial. Crystalline schists of the fundamental complex are

abundant and of many colors. If he could have viewed them they would surely have gladdened the heart of Johannes Lehmann. Had the grand old pioneer in the field chanced to dwell in this country instead of Saxony the Erzgebirge might never have become so famous; and *Die Untersuchungen über Entstehung der altkrystallinischen Schiefergesteine* might have had the desert range of New Mexico for the central theme of his great epic.

The massive plutonic rocks, the granites, diorites, gabbros, and diabases, cut and intrude the pre-Cambrian complex in all directions. Their surface types appear to have utterly disappeared, probably during the long periods of erosion as indicated by the great unconformities.

Volcanics belong to all ages from the Cretaceous onward. San Mateo is one of the majestic volcanic piles of the continent. It now stands perched high upon a lofty Cretaceous pedestal. A forest of volcanic necks stretches away to the northward. Modern basalt flows cover hundreds of square miles. Older lava streams constitute the resistant cap of many plateau plains. Intrusive sheets run for scores of miles across the plains like great walls of cyclopean masonry. Laccolithes (Fig. 3) display their tectonic origin rather than formation through simple hydrostatic welling. Cinder cones are numerous (Fig. 4). Beside the fine cone of Capulin that of famed Vesuvius sinks into utter insignificance. The phenomena of classic Auvergne and the Phlegræan fields are reproduced again and again but on grander scale.

Stratigraphical succession in New Mexico is instructive to an extraordinary degree. It is, perhaps, the most complete to be found in any state in the Union. Curiously enough, above the pre-Cambrian crystalline complex highly resistant rocks compose the lower half of the geological column; while in strong contrast weak friable beds are segregated in the upper half. With a close-patterned orogeny this disposition has telling effect upon the final relief expression.

The geological column attains an enormous thickness. Archeozoic, Proterozoic, Paleozoic, Mesozoic, and Cenozoic sections are each about 10,000 feet in vertical measurement. Altogether there are 50,000 feet of strata reposing upon the non-clastic Azoics. It is

one of the great critical sections of the country. It is in reality the standard succession of the Western continent. It is a rock sequence such as James Hall vainly sought in his lifelong endeavor

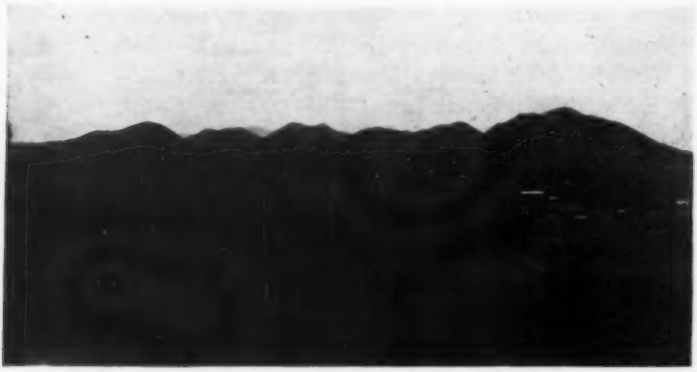

FIG. 3.—Uncovered laccolith of Multiplex Ortiz

FIG. 4.—Zuni Salt Lake: birth of a volcano. Two cinder cones on floor of explosive crater, 600 feet deep.

to establish a standard stratigraphy for the world. It thrice transcends the united sections of Murchison, Sedgwick, and Lonsdale. With the depositional equivalents of its numerous hiatuses

it constitutes the longest and best sedimentative record of which we know.

Huge as is the sedimentative prospect, erosive depletion looms up in even vaster proportions. Thirty major unconformities stand for a very much longer interval of time than that which deposition occupied. Nowhere else on the face of the earth does it seem that the stratigraphic record is so clearly defined for a perfectly independent classification of geologic terranes according to diastrophic movement. It is the one place of all where orotaxial principles should sustain themselves under severest test. Any world-scheme of formational arrangement must stand or fall when fitted to this titan among rock sections.

That the pre-Cambrian rocks beyond the southern Rocky Mountains have never received the attention which they really merit recent disclosures amply attest. It seems possible that some day ere long they will divulge as clear a succession as did the transition rocks to English geologists a century ago. At least this is certainly the most promising field for new and large results that the American continent today offers in stratigraphy.

Three grand successions are presented. There is first at the top a thick section composed of relatively slightly metamorphosed and mildly deformed rock masses; then, in the middle, separated above and below, by a great erosional unconformity, a sequence of terranes highly altered, closely flexed, and repeatedly broken through by eruptives of various types; and third, at the bottom, an intensely metamorphosed and sheared complex in which no signs of classic origin are discernible. These grand successions are respectively Proterozic, Archeozoic, and Azoic.

To the Azoic basement are referred all of those lowest pre-Cambrian masses which, intensely altered and profoundly deformed, present no evidence of sedimentary origin. If any such classic character ever existed all trace is now completely obliterated. This intensely metamorphosed complex lying at the very bottom of the exposed rock column is a new find. Its discovery is yet too recent to enable its full significance to be properly evaluated.

Composing this fundamental complex are mainly thinly foliated gneisses, micaceous schists, squeezed granites, and other sheared

eruptives. The slightly altered granites, diorites, and diabases which cut the mass are manifestly relatively late intrusives.

Their evident enormous extent, their intensely metamorphosed condition, their extensive deformation, their sharp lithologic contrast with the superior metamorphics, and the marked erosional unconformity dividing the two successions all attest the supreme antiquity of the complex. The depositional equivalent of the summital unconformity may itself surpass in duration the stratigraphic record of the entire Paleozoic section. The best developments of the typical non-clastic Azoics are in the southwestern portions of the state.

The Archeozoic platform is bounded both above and below by marked erosional planes of unconformity. The rocks are all highly metamorphosed. The presence of quartzites, slates, and marbles indicates the clastic origin of a large part of the mass. The section is very thick, possibly not less than two miles.

In marked contrast with the inferior Azoic rocks are the evidences of a clastic origin of the major portion of the section, and a distinct lithologic sequence is plainly discernible. Unconformities which are associated may correspond to those shown in the Grand Canyon, but it is believed that some of the latter are superposed in New Mexico. It is really the Archeozoic rocks chiefly which heretofore have been called Archean, the Azoic masses not being recognized and the Proterozoic segregation not being differentiated.

A thick sequence of pre-Cambrian clastics which are only slightly altered is displayed in the Tijeras Canyon, in the Sandia Range east of Albuquerque, where in a sharp fold a mile of strata outcrops in continuous horizontal section. In discontinuous exposure at least another mile of beds is evidently present. The strata are chiefly shales, locally more or less indurated with some quartzite beds and intrusive granites.

The quartzite beds which stand at high angles are commonly mistaken for immense quartz reefs, and under such misconception they are extensively prospected for gold. Microscopical examination in thin slices demonstrates conclusively that the rock has a clastic origin, and that it is an old sandstone indurated by the

interstitial deposition of silica disposed in optical continuity with the separate sand grains. The enormous thickness of the shales is especially noteworthy. It is probable that eventually they will yield an extensive fauna, or a succession of faunas. Should the rock section prove fossiliferous the opportunity for determining faunal sequence would certainly be as favorable as among any Paleozoics of the continent.

Where the crest of the great Tijeras fold of the Proterozoics is deeply beveled off flat-lying limestones of latest Paleozoic age recline directly upon it. This notable unconformity plane represents a period of time of vast duration, one almost coextensive with the Paleozoic era. No less than ten great erosion intervals are superposed one upon another.

Although the early Paleozoic strata are entirely absent over the northern half of New Mexico they are extensively developed in the southern part of the state. There some of the major terranes were identified and correlated with the European sections almost as soon as they were in the Upper Mississippi Valley, or within a decade of the first appearance of Murchison's and Sedgwick's classic works.

When in 1874 undoubted Cambrian beds were first recognized by Jenney in New Mexico only unimportant sandstones were disclosed in the Franklin Mountains north of El Paso. Since that date the extent of the section has been greatly expanded, until now over 1,000 feet of sandstones, quartzites, and limestones are known. Westward these formations connect with the great Cambrian sections of Arizona.

As indicated by the contained fossils both mid- and late-Cambrian sections are fairly well represented, the former by about 700 feet of strata and the latter by 400 feet. There are no evidences of the presence of early Cambrian beds within the borders of the state, and it does not seem likely that any ever will be found.

Ordovician strata were the first Paleozoic rocks recognized within the limits of New Mexico. As early as 1848 Wislizenus recorded the finding of Ordovician (lower Silurian) fossils in rocks west of El Paso. A few years later both Shumard and Antisell

discovered similar organic remains in the mountains lying to the north of the same point. The section developed rapidly until it reached a thickness of more than 500 feet, extended entirely across the southern part of the state, and comprised three important series corresponding to the three subdivisions of the period.

These limestones are abundantly fossiliferous. The forms indicate the same sub-periodic divisions that are commonly recognized on the eastern side of the continent. Much of the bottom and top of the general section for the continent is missing in New Mexico. Between the Ordovician beds and the Cambrian below and the Silurian above marked unconformities prevail so that the first-mentioned unit is sharply defined.

Silurian sediments are poorly developed. The rocks out-crop in a thin broken line across the southwestern corner of the state. That deposition during the period was extensive in this region is quite manifest; but it is also evident that during Devonian and Mississippian times the deposits were largely removed through profound erosion. The contained fossils indicate only the Niagaran horizons of the standard eastern section.

From the character of the organic remains the presence of Devonian rocks in New Mexico receives early announcement. Both Antisell and Hall in 1856 call attention to the fossil evidence. Dutton's statement that Devonian strata were generally wanting in the eastern part of the Colorado High Plateau region is somewhat misleading. These rocks are really very much better represented in southwestern New Mexico than has been commonly supposed. In the vicinity of Santa Rita, in Grant County, are 400 feet of light-colored, fine-grained limestones and shales which carry abundant organic remains.

Two parts of Devonian time appear to be represented. The basal shales seem to belong to the mid-Devonian section; while the limestones are late Devonian in age. A surprising feature is that the fauna is the typical Lime Creek phase of northern Iowa. This horizon corresponds to the uppermost part of the section represented in the Upper Mississippi Valley, which is, according to Tschernyschew, Williams, and others, who have given the subject most attention, mid-Devonian in age. These authorities also

agree on the appearance of the fauna in the West, or Mississippi Valley region, much earlier than in the East, or New York province; so that, although its age in the first-named locality is strictly mid-Devonian, in the second locality it is late Devonian. This being the case, the same migratory fauna may have put in an appearance in the southwestern or New Mexican province, considerably earlier even than it did in the Upper Mississippi Valley region—possibly in the middle or latter part of early Devonian time.

The Mississippian succession in New Mexico comprises only a limited portion of the middle division of the Mississippi Valley section. Both the upper, or Tennesseean, and the lower, or Waverleyan divisions seem to be entirely missing. Because of its restricted representation and its other notable peculiarities the southwestern sequence is designated the Socorran series. The maximum thickness of these rocks is about 400 feet.

Both the Chouteau and Burlington faunas of the Mississippi Valley are well represented. The list of organic remains is almost as extensive as that of the type localities. Fossils from the Modoc limestone, which extends eastward from Arizona, indicate higher horizons, probably so high as the Keokuk level. Curiously, the huge gastropods which are so rare in the East are very abundant in the Southwest.

The especial importance of the New Mexican section of the Mississippian rocks is that it directly connects the eastern or Ozark sequence with that of the Far West. Summing up the evidence regarding these strata as they are represented around the border of the Colorado High Plateau it appears that there is in the Southeast and South, in southwestern New Mexico and eastern Arizona, the Socorran series; in the West, in northwestern Arizona, the Lower Red Wall formation; in southwestern Colorado the Ouray (upper part) limestone; and east of the southern Rocky Mountains the Millsap limestone. In New Mexico the succession is probably most completely represented and most varied, although perhaps not including all that is represented in Colorado.

In strong contrast with the Pennsylvanian sequence of the middle and eastern portions of the continent the southwestern succession is almost unbrokenly calcareous. A single plate of

limestone, which extends over the entire area of the state, reaches far into Texas on the one hand, and on the other hand completely over the Colorado dome to the Grand Canyon, where it appears as the Aubrey limestone, has in New Mexico a thickness of 5,000 feet.

These unbroken limestones are the open-sea analogues of the coastal coal measures of the Mississippi Valley. Where in Iowa they are mainly represented by a great erosional interval, and in Arkansas by 20,000 feet of shore deposits, in the New Mexican field coal-bearing measures are all but completely vanquished. Something of the enormous Arkansan series seems to find expression in the diminutive Ladronesian series with its bare 200 feet of Alamito shales and a scant foot of coal. The last-mentioned formation, which no doubt was once one of very considerable magnitude, is almost effaced through erosion which took place before the laying down of the limestones, which in marked unconformity rest directly upon these shales.

Pennsylvanian, or upper Carboniferous, limestones attain a thickness of 2,000 feet in northern New Mexico. There they recline directly upon the surface of the old pre-Cambrian basement, all else of the Paleozoics being absent. In the South, where they reach a measurement of upward of 5,000 feet and are known as the Hueco succession of limestones, they repose successively upon Mississippian, Devonian, Silurian, Ordovician, and Cambrian formations.

In the North the great limestone plate is best known in the lofty Sandia and Manzano ranges, east of Albuquerque. Throughout this district it appears to be broadly separable into two strongly contrasted formations—a lower shaly and black limestone, and an upper member comprising chiefly massive blue and gray limestones. To the inferior member, 1,000 feet thick, the title "Lunasian series" is given. To the upper sequence, also about 1,000 feet in thickness, the term "Maderan series" seems most appropriate.

On the basis of the determined faunal characteristics the stratigraphical position of the Lunasian series appears to correspond nearly with that of the Missourian series of the Mississippi Valley. Upon the same grounds the Maderan series is paralleled

with the Oklahoman series of the eastern field, but which some Kansas workers are prone to correlate with the far-off Permian rocks of the Russian Urals (Fig. 5).

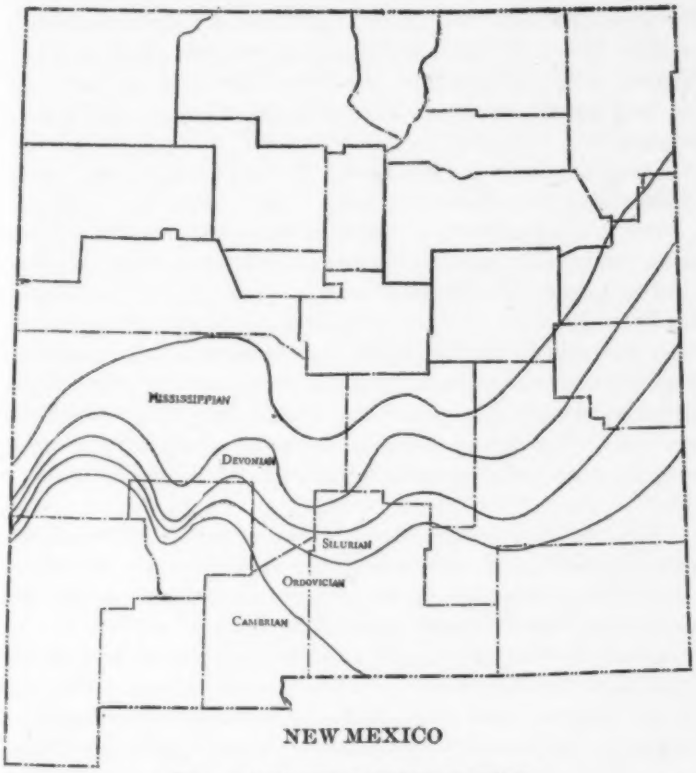

FIG. 5.—Areal range of periodic formations

As Pennsylvanian time was ushered in with the deposition of sands and clays, so also did it close. Succeeding the huge limestone plate is the Bernalillan series of "Red Beds." As first pointed out in 1904[1] the "Red Beds" problem which so long had baffled

[1] *Report of the Governor of New Mexico to the Secretary of the Interior for 1903*, p. 339 (Washington, 1904).

geologists found a ready solution in the discovery that these deposits were not accumulations of a single geologic age, but, in their different parts, of three distinct ages. Beds of similar lithologic aspect of Pennsylvanian, Permian, and Triassic ages were directly superposed, the normally intervening formations being absent. This was, then, the real explanation why different investigators in different localities had determined such diverse dates for their several sections. Even the unconformity planes were overlooked.

The recognition of "Red Beds" of Pennsylvanian age was a distinct advance in the stratigraphy of the Southwest.

It is a curious travesty on the fates that despite the acrimonious controversy which waged for more than a full generation over the possible presence of Permian beds in America, the one section which would have most speedily ended it remained unnoticed, albeit its fossils had long been fully made known. As early as 1860 Shumard described what he distinctly designated a Permian fauna from the Sierra Guadalupe on the New Mexico–Texas boundary; but its true significance remained in complete obscurity for half a century, when Girty accidentally pointed out its global relationships.

Although the Guadalupan succession of sandstones and limestones is nearly 4,000 feet thick at the typical locality the formation rapidly diminishes in force to the northward. Before the Sandias are reached the Bernalillan "Red Beds" and the Cimarronian "Red Beds" are brought together to form an uninterrupted "Red Beds" section.

Cimarronian "Red Beds" clothe the backslope of the Guadalupe Mountains and extend northeastward far into Kansas. There, and through the Panhandle of Texas, they are in turn overlaid by Triassic "Red Beds." The fact that a marked erosional unconformity separates the two terranes is a recent observation. To the northwest similar merging of "Red Beds" in continuous sequence obtains; and the Triassic Doloresian formation immediately succeeds Cimarronian deposits.

In New Mexico the strata of Triassic age are predominantly typical "Red Beds." There are two series of red shales and sand-

stones separated by an erosion interval. The earlier of the two series is confined to the east side of the Rockies, while the later one is represented chiefly on the west side of the Cordillera. Their total thickness is nearly 2,000 feet.

Like the Triassic sediments the Jurassic succession comprises an earlier and a later series, set off from each other by a great erosional unconformity. Together they represent a column 1,200 feet thick. The Morrisonian series is chiefly composed of argillaceous deposits. Of these the Chaquaqua (Chicago) shales occupy one-half of the entire section. They are underlaid by a basal sandstone. A notable erosion unconformity separates them from the succeeding Comanchan deposits.

When in the early fifties of the last century Jules Marcou, colleague and exiled compatriot of Louis Agassiz, fresh from the Jura Mountains, introduced into this country the European title "Jurassic" it was the Tucumcari section in eastern New Mexico that was involved. Around this Cerro Tucumcari raged a storm center for a full generation. After being overborne by sheer weight of numbers and after being submerged for seventy-five years Marcou finally comes into his own. Cerro Tucumcari proves to contain the full Jurassic section of the region. Marcou erred only in including some of the Dakotan sandstone layers.

The important Comanchan succession of Texas and the Gulf region finds but feeble representation in New Mexico, and then only as an attenuated border which soon vanishes completely against the Cordilleran uplift. The basal limestones of Texas are traceable around the Llano Estacado. The shales extend farther. Erosional unconformity separates its two series, and like sedimental breaks mark both top and bottom of the sequence. Because of the fact that the thin shale beds are immediately under the massive Dakotan sandstone they usually escape notice.

The basal Dakotan sandstone of the Cretaceous succession is especially noteworthy by reason of its very wide geographical distribution. In the Rocky Mountain region it is further remarkable because of its disposition on an old peneplain surface, which, although much deformed, now coincides with the tops of the highest peaks. Where the southern Rockies plunge in a triple fold

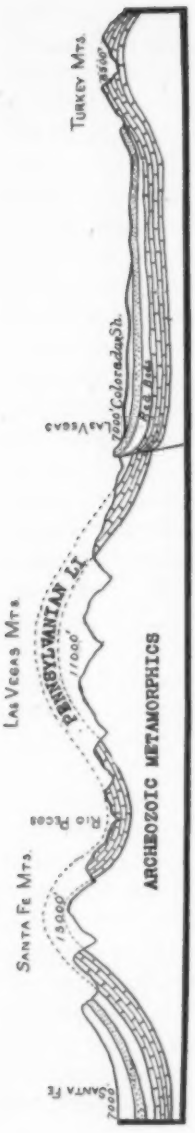

Fig. 6.—Ceja Glorietta: end of the Rocky Mountains

beneath the general plains' surface of the Mexican table-land the Dakotan sandstone forms a magnificent inward-facing escarpment. Along the steep interior face the Atchison, Topeka, & Santa Fe Railroad skirts for a distance of fifty miles. There, as elsewhere on the continent, the Dakotan sandstone is one of the geological landmarks of the region. With a thickness of 300 feet it is, perhaps, the most extensive basal sandstone of which we know (Fig. 6).

Immediately following the Dakotan sandstone is a fine succession of marine shales and limestones, which in New Mexico have a thickness of upward of 2,000 feet. This is the Coloradan series. A quite unusual feature is that the series preserves its subdivisional integrity through a distance of 1,000 miles, to Iowa and Minnesota, on the far side of the Continental Interior basin.

A succeeding 2,000 feet of strata comprising sandstones and shales constitute the Montanan series. It is an important coal-bearing formation, containing a larger fuel supply than do the coal measures of the entire Mississippi Valley. In early accounts of the region these coals were all regarded as Laramian in age. Locally the coal seams overlying the Ortiz laccolith are changed into high-grade anthracite, the quality of which compares favorably with the best hard coals of the Appalachians. East of the Rockies the Montanan beds merge into the marine Pierre shales.

As the uppermost member of the Cretaceous section the Laramian series embraces only a small part of the beds formerly paraded under this title. By divesting the old Laramie section of that portion which is really Tertiary in age the long drawn-out controversy concerning the true age of these beds comes to an abrupt end.

With the principal coal beds referred to the Montanan series below and the Ratonan series above the so-called Laramie formation of New Mexico becomes almost as barren as the marine Coloradan series. Still, in the northwestern part of the state, the Pictured Cliffs sanstones and the Navajo shales attain a thickness of nearly 1,200 feet.

Tertiary sedimentation in the New Mexican area begins with beds the deposition of which seem long to antedate the earliest Eocene formations of other parts of the world. When in the course of coal investigations in 1906 a marked erosional unconformity and basal conglomerate were found in the lofty Raton Mesa about 1,500 feet below its massive lava cap, it was surmised that the solution of the Laramie problem had been stumbled upon and that above the erosion plane the beds were really Tertiary in age, while those beneath that line were Cretaceous. These conclusions were fully substantiated a decade later by Lee in an elaborate monograph on the geology of the region.

The Ratonan series is, then, older than the oldest Eocene deposits of the state, the Puerco beds, which, since the days of Cope in the region, were believed to be the earliest Tertiaries extant. It is an important coal-bearing section, which fact probably largely accounts for its early confusion with the original Laramie coal formations of the more northern Rocky Mountains districts. The erosion plane upon which the Ratonan sediments rest is a peneplain of wide proportions evidently worn down on the entire southern Rocky Mountains province. In its production no less than a mile of rock was removed.

The Aztecan series is represented by a basal conglomerate of very considerable thickness. Beyond the borders of the state the Arculeta conglomerate is succeeded by shales. No sediments are correlated with the erosional interval below. It is possible that

the basal unconformity is coextensive with the one beneath the Ratonan series on the opposite side of the Rockies, in which case the Arculeta and Maya formations are homotaxial. The term "Animas," which is sometimes applied to the beds of the San Juan basin is preoccupied.

In the Nacimientan series are included the basal beds of the old Wasatch group. It is regarded as earliest Eocene. It is subdivided into the Puerco clays and the Torrejon marls and sandstones. The deposits are doubtless entirely epeirotic in character and perhaps eolian. There is a large and varied vertebrate fauna. The outcrop constituted one of Cope's favorite collecting grounds. The beds have a maximum vertical measurement of 1,000 feet. Marked erosional unconformities separate all of the Tertiary terranes of the San Juan basin.

The Chaman series comprises the main body of clays, sands, and shales of the San Juan Wasatch succession. Canyon Largo sandstone is Newberry's early designation. Chaco terrane covers the principal clay deposits. Together they are nearly 2,000 feet thick.

Of manifest later date are the Tertiaries of the Rio Grande basin. These consist of the Galesteo sands and the Santa Fe marls, 1,300 feet in thickness. Over the Llano Estacado the latest Tertiary sands, 300 feet thick, are assigned to the Pecosian series.

The terranal names applied to the New Mexican Tertiaries cover only the main bodies of deposits. No doubt other titles will eventually be attached to the numerous minor members.

Quaternary deposits of New Mexico are chiefly desert concentrates. They are not mainly deflated materials, but accumulations left behind after the main bulk of fine rock débris has been sorted out and exported. The deflated dusts come to rest far outside of the arid region. Gravel and bowlder trains are principally the results of arroyo wash. Till-like materials are brought down from the highlands. Some glacial till yet remains on the sides of the highest mountains where ice fields were once feebly represented. Adobe soil is deflated dust temporarily at rest. Some fluviatile deposits are present. Lacustrine beds are rare, very limited, and quite ephemeral.

In the accompanying chart of New Mexican terranes the latter are fitted to the Chamberlin and Salisbury classification.

GENERAL GEOLOGICAL SECTION OF NEW MEXICO

Eras	Periods	Series	Terranes	Thickness in Feet	Rocks
Cenozoic	Present	Jornadan	.....	25	Adobe
	Pleistocene	Palomasan	.....	200	Till
		Gilan	..... ?	250	Gravels
			Interval	.....	Unconformity
	Pliocene	Pecosian	Llano E.	300	Sands
			Interval	.....	Unconformity
	Miocene	Arriban	Santa Fe	500	Clays
			Galesteo	800	Sands
			Interval	.....	Unconformity
	Oligocene	Chaman	Chaco	1,000	Clays
			Canyon L.	700	Sandstones
			Interval	.....	Unconformity
	Eocene	Nacimientan	Torrejon	300	Marls
			Interval	.....	Unconformity
			Puerco	500	Clays
			Interval	.....	Unconformity
		Aztecan	Archuleta	250	Conglomerate
			Interval	Great	Unconformity
	Arapahoe	Ratonan	Maxwell	800	Shales
			Houten	600	Sandstones
			Maya	100	Conglomerate
			Interval	Great	Unconformity
Mesozoic	Cretaceous	Laramian	Navajo	1,000	Shales
			Pictured Cl.	150	Sandstones
			Interval	.....	Unconformity
		Montanan	Lewis	600	Shales
			Chacra	200	Sandstones
			Mesa Verde	800	Shales
			Pina Vititos	250	Sandstones
			Interval	.....	Unconformity
		Coloradan	La Jara	1,000	Shales
			Apishapa	500	Shales
			Timpas	300	Limestones
			Gallinas	200	Shales
		Dakotan	Glorietta	300	Sandstones
			Interval	Great	Unconformity

GENERAL GEOLOGICAL SECTION OF NEW MEXICO—*Continued*

Eras	Periods	Series	Terranes	Thickness in Feet	Rocks
MESOZOIC	Comanchan....		Kiowa.....	100	Shales
			Garrett.....	50	Conglomerate
			Interval.....	.....	Unconformity
			Washita.....	500	Limestones
			Fredericksburg	200	Limestones
	Jurassic.....	.....	Interval.....	.....	Unconformity
		Morrisonian...	Chaquaqua...	150	Shales
			Travester.....	100	Shales
			Exter.....	75	Sandstones
		.....	Interval.....	.....	Unconformity
		Zunian.....	McElmo.....	300	Shales
			La Plata.....	300	Sandstones
	Triassic.....	Doloresian....	Wingate.....	900	Sandstones
			Le Roux.....	800	Shales
			Shinarump....	600	Conglomerate
		.....	Interval.....	.....	Unconformity
		Dockuman....	Trujillo.....	300	Shales
			Tecovas.....	200	Shales
			Interval.....	.....	Unconformity
PALEOZOIC	Permian.....	Cimarronian..	Quarterm.....	150	Shales
			Greer.....	125	Shales
			Chaves.....	425	Shales
			Interval.....	.....	Unconformity
		Guadaloupan..	Capitan.....	2,500	Limestones
			Eddy.....	1,000	Sandstones
			Interval.....	.....	Unconformity
		Bernalillan...	Torrance.....	500	Shales
			Yeso.....	600	Shales
			Manzano.....	500	Sandstones
			Interval.....	.....	Unconformity
		Maderan.....	Tellera.....	300	Limestones
			Gallegos.....	100	Sandstones
			Antonito.....	200	Limestones
	Pennsylvanian	Lunasan.....	Mosca.....	200	Limestones
			Coyote.....	75	Sandstones
			Montosa.....	400	Limestones
			Sandia.....	250	Shales
			Interval.....	Great	Unconformity
		Ladronesian...	Alamito.....	200	Shales

GENERAL GEOLOGICAL SECTION OF NEW MEXICO—*Continued*

Eras	Periods	Series	Terranes	Thickness in Feet	Rocks
PALEOZOIC	Mississippian..	Tennessean...	Interval.....	Great	Unconformity
		Socorran.....	Modoc.....	200	Limestones
			Sierra.....	50	Limestones
			Lake Valley...	150	Limestones
			Grande.....	25	Limestones
		Waverlyan....	Interval.....	Great	Unconformity
	Devonian.....	Martinian....	Berenda.....	50	Limestones
			Interval.....	.....	Unconformity
		Perchan.....	Bella.....	250	Shales
			Silver.....	200	Shales
			Interval.....	.....	Unconformity
	Silurian.....	Santa Ritan...	Interval	.....	Wanting
			Naiad.....	250	Limestones
			Cibola.....	175	Limestones
			Interval.....	.....	Unconformity
PALEOZIC	Ordovician....	Mimbresian...	Cristobal.....	165	Limestones
		Montoyan....	Frondosa.....	100	Limestones
		El Pasan.....	Armendaris...	300	Limestones
			Interval.....	.....	Unconformity
	Cambrian....	Chiricahuan...	Lone.....	300	Quartzites
		Chloridian....	Carrasco.....	75	Limestones
		Dragoonan...	Burro.....	500	Quartzites
			Hawkins.....	50	Limestones
			Mangas.....	100	Quartzites
			Interval.....	Great	Unconformity
PROTEROZOIC	Superorian....	Valencian.....	Graphic.....	1,000	Lavas
			Sandoval.....	.....	Granites
			Interval.....	Great	Unconformity
	Selkirkian....	Albuquerquan.	Ysidro.....	1,500	Shales
			Tijeras.....	250	Quartzites
			Interval.....	.....	Unconformity
		Garnuan.....	Antonio.....	2,000	Shales
	Anian		Interval.....	Great	Unconformity

GENERAL GEOLOGICAL SECTION OF NEW MEXICO—*Continued*

Eras	Periods	Series	Terranes	Thickness in Feet	Rocks
Archeozoic		Pecurisan	Truchas	900	Slates
			Penasco	400	Quartzites
			Serna	1,500	Schists
			Interval	Great	Unconformity
		Taosan	Solitario	800	Slates
			Rociada	250	Limestones
			Sapello	300	Quartzites
			Ninos	1,000	Schists
			Interval	Great	Unconformity
Azoic	.....	.....	.....	.....	Slates, Gneisses, Schists

For general completeness the New Mexican rock-pile stands *facile princeps* among American geological sections. Being at once both a critical and a standard terranal succession for the continent, it merits and invites closest inspection, carefulest evaluation, and widest comparison. It reflects regional crustal movements along a primitive continental plait more directly and more perfectly than perhaps any other known section. Amplitude of diastrophic oscillation is sufficiently large and sharp to make this a direct basis of genetic taxonomy. It admits of orotaxial classification of geological formations at its best.

MOVEMENTS IN CRYSTALLIZING MAGMA

FRANK F. GROUT
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The study of the crystallization of silicate melts has led to many important conclusions regarding igneous magmas, several of which are stated in papers recently issued from the Geophysical Laboratory with the authority of actual experience behind them. Where facts have been discovered, however, concerning a particular hypothesis there has been a tendency to minimize the probability of some other quite independent hypotheses and to carry the conclusions along into regions not covered by experimental data. In several papers since the publication of Bowen's important outline of the evolution of igneous rocks[1] the present writer has endeavored to reopen consideration of some hypotheses lightly brushed aside in that paper. The arguments have brought forth some new light, but much still remains to be done.

Liquid magma is known to move as it is intruded, and by convection. Crystallizing magma (to accept a usage that seems to be approved) is also known to be moved by intrusion and convection, and there are molecular movements by diffusion; in addition there are probably differential movements as crystals settle or float out of magma, and there may possibly be a straining or filter-pressing away from crystals. The magnitude of diffusion is pretty definitely settled by Bowen.[2] Little question has arisen over the movements of intrusion, but there is still question as to (1) the activity of convection at depth, (2) the effectiveness of crystal settling, (3) the mechanics and effects of filter-pressing.

[1] N. L. Bowen, "The Later Stages of the Evolution of Igneous Rocks," *Jour. Geol.*, XXIII, Supplement, November-December, 1915.

[2] N. L. Bowen, "Diffusion in Silicate Melts," *Bull. Geol. Soc. Amer.*, XXVII, p. 48.

CONVECTION

In making an estimate of the rapidity of convection[1] an argument was built up by starting with a variety of assumptions. This was done because several writers had assumed, without any suggestion of calculation, that the magma was too viscous to circulate. The value of assumptions not based on quantitative data may be illustrated by references to the effects of viscosity. Harker approves diffusion, but considers the magma too viscous to allow settling of crystals. Daly approves settling, but considers the magma too viscous to allow convection. Pirsson approves convection, but considers the magma too viscous to allow diffusion. Thus we get around the circle and all processes are still worthy of consideration.

The results of calculation, in actual figures, indicate great probability of some circulation. The calculated rates are not to be taken as at all accurate. Neither is it important to distinguish whether cooling, gas phase, or crystal phase is the dominant cause.[2] The evidences are sufficient to indicate some active circulation. Bowen says now that he has never doubted the reality of convection in magmas.[3]

The contrast presented in a paragraph headed "Crystal Settling vs. Convection" is apparently misleading. The present writer had no thought of differentiation except through the agency of crystallization. Convection seemed a necessary factor in explaining the combination of banded and fluxion structures. It is argued that the rhythm of settling would give the same banding as rhythm

[1] Frank F. Grout, "Two-Phase Convection in Igneous Magmas," *Jour. Geol.*, XXVI (1918), pp. 481–89.

[2] Bowen in a later paper questions whether the two-phase idea can be extended to aggregates of crystal and liquid. Let him try it. Simply suspend crystals in side of dish and release. His own reference to heavy liquid separations indicates that he has had experience with an operation in which two-phase convection is very common.

[3] N. L. Bowen, "Crystallization-Differentiation in Igneous Magmas," *Jour. Geol.*, XXVII, p. 412. One would certainly infer a doubt from the statement in the earlier paper, p. 12: "The same objections apply to the supposed maintenance of approximate uniformity . . . . through the agency of convection currents. . . . ." Certainly convection would *tend* to keep the composition uniform, and one would infer that since the magma does not remain uniform he saw no evidence of convection.

in currents. To this there is no question at all. But, in addition to banding, the Duluth rocks show an *orientation*. The combination is explained only by circulation.

Convection, as a general stirring, may be supposed to interfere with crystal settling. Probably in one sense this is true, for any liquid containing sediments clears more rapidly if left quiet. But the arguments for a circulation at Duluth are conclusive and have not been answered. Settling, if it occurred at all (and it probably did), occurred during circulation. Since the calculated rates of motion indicated that convection was more rapid than settling,[1] it is clear that convection might aid in bringing a crystal formed at the top of a magma chamber to some point near the bottom. Then as the current moved along the floor there might be settling enough to cause the growth of a rock layer at the bottom. Settling, however, is not the only process by which rock may grow. Simple cooling makes the shell of solidified wall or floor increase in thickness. The bottom layer of the moving current may become part of the floor by cooling and increasing in viscosity as well as by settling. Thus it may happen that even when circulation tends to prevent settling some settling may occur, and certainly some rock may accumulate along the floor.

In order to "make a case" for convection certain complications in the process were omitted in the original paper.[2] No doubt convection is far from a simple motion in large sheetlike chambers. There are the irregularities in the banding of most banded igneous rocks to prove the complexity of motion. There may even have been an approach to the theoretical hexagonal cells[3] of circulation. These, however, would have little effect on the result. No crystals would deposit on the sides of a cell—there is no support on the walls of such cells. Deposition would occur in bands on the bottom, almost as if the circulation was the simple case described.

[1] Frank F. Grout, *op. cit.*, p. 494.

[2] Unfortunately an error occurs in the copy of the calculation for gas-phase convection, *op. cit.*, p. 491: "lbs. per sq. inch" should be *atmospheres*. It seems correct values were used in calculation, but stated wrongly in copying.

[3] See *Jour. Geol.*, XXIV, pp. 219 ff.

CRYSTAL SETTLING

The reality of the separation of crystals from liquid magma by gravity has been clearly shown.[1] In crucibles a few centimeters deep, crystals formed and settled and grew to considerable size.

In order to determine equilibrium relations, efforts were made in the laboratory work to maintain uniform conditions of heat through the whole melt. Contrasted with these conditions are the large size and irregular cooling of intruded magmas. A temperature variation of 100° C. is not unlikely in the viscous liquid beginning to crystallize. If crystals form in a cooling top layer and settle to a hot interior layer they remelt and make the magma heterogeneous. Eventually the continued settling of crystals may so cool the central part of the magma that the crystals formed near the top settle through the central part without either growth or solution. It would take so long for this balance to be attained, however, that it seems likely that the roof phase would grow as a solid before many crystals settled. Meanwhile in any large mass the cooling sides of the chamber would start convection and entirely modify the situation. The probability seems to be that chambers a few feet thick are chilled; up to 100 feet crystal settling may be the dominant effect, but in larger chambers convection stirs things up too much. Settling a few feet removes crystals from the circulating magma.

The condition of the gabbro at Duluth was taken as a sign that no great amount of settling occurred,[2] and Bowen agrees that simple settling does not adequately explain the series of rocks developed. He finds it possible still to refer to the peridotites as a result of settling. They are bands, like other bands in the gabbro, and if most of the bands are not the result of settling it seems inadvisable to select the peridotites to support the original idea.

In a remark on the banded structure at Duluth, Bowen says that if crystallization is rhythmic, crystals brought down to the bottom by settling would result in precisely the same alternation as

[1] N. L. Bowen, "Crystallization Differentiation in Silicate Melts," *Amer. Jour. Sci.*, XXXIX (1915), p. 186.

[2] Frank F. Grout, "A Type of Igneous Differentiation," *Jour. Geol.*, XXVI (1918), p. 639.

if brought down by convection. In this he is wholly correct and no advantage is claimed for convection. It is only when the banding is accompanied by an orientation of grain that the evidence is strong against crystal settling. It is not the banding nor the parallelism which determines the process, but the combination of bands with a foliated structure. This was emphasized in the original papers.[1] As there stated, crystal settling is to be thought of as a matter of a few feet, not thousands of feet.

FILTER-PRESSING

A process of expulsion of residual fluid magma from a mass after a large proportion of the material had crystallized is advocated by Bowen and Harker. Preliminary suggestions of the idea are credited by Harker to Barrow and to Judd (who refer also to Osann, Teall, and Geikie).

In tracing these earlier statements of the idea, no good outline of the mechanics or general results could be found. Teall and Osann and Harker[2] describe patches of glassy or residual magma filling steam cavities when the gas of the cavity has been absorbed or condensed, or has escaped. No one can question the occurrence of rounded lumps formed from magma, but the source of the lumps and the process by which they got there, and the ultimate removal of any gas that may have been there, are hard to understand. If the magma was liquid enough to "ooze out from among the crystals" the gas just separated from the magma could hardly be absorbed, condensed, or allowed to escape, leaving a spherical hole. Barrow[3] has described a pegmatitic separation from granite, as have many others. In many cases this may be a process of separation of liquid from partly crystalline magma, but pegmatites are most readily explained by the readier penetration of thinly fluid *emanations* in advance of viscous magma. This is more nearly analogous to immiscible separation than to filter-pressing. Filter-pressing

[1] Frank F. Grout, "Internal Structures of Igneous Rocks," *Jour. Geol.*, XXVI (1918), p. 455.

[2] A. Harker, *The Natural History of Igneous Rocks*, pp. 324–25. Macmillan, 1909.

[3] George Barrow, "On Certain Gneisses and Their Relation to Pegmatites," *Geol. Mag.*, 1892, pp. 64–65.

involves differential pressures, and no such pressures are evidenced by the great majority of granites having pegmatitic facies. Barrow also refers to a case of straining off of magma into crevices too small for crystals to get in. Such an action is easily understood but would not be expected to produce large bodies of rock. Barrow goes on to say, however, that "the continuance of the pressure will still further force the liquid from the solid crystals, leaving at last just sufficient of the magma to fill the interstices between them." This can hardly be considered a clear outline of what happens "further" than the oozing of magma into cracks too small for the crystals to enter. Judd[1] has described andesite and pitchstone intrusions which he thinks separated by a process of "liquation"—apparently a growth of crystals along the walls leaving a residue of different composition. Harker, referring to the suggestion, says "it is easy to conceive of various modes of liquation and decantation, straining and filtration by which a partial separation may be brought about." Bowen has shown the improbability of diffusion sufficient to yield much differentiation by any liquation in this sense. "Decantation" is not a process of filter-pressing. To the present writer "straining and filtration" of a magma on any large scale are not easily conceived.

Harker reviews these descriptions, emphasizing the case of pegmatites and that of pitchstones related to andesites. He does not refer to any indication of a process of compression except in the case of numerous small pegmatite intrusions related to large granite gneisses. Even here the larger masses of pegmatite are better explained by a separation of some other sort.

Bowen presents the latest development of ideas on filter-pressing.[2] His first analogy is to the squeezing out of water from sand on a wet beach. There is little question that such a mesh of crystals as he suggests, up to 80 per cent of the total mass, might, when subject to differential pressure, give way and result in closer packing.

The supposed filter effects are described for three different cases, but no mention is made of the case of pegmatitic separation sug-

[1] J. W. Judd, *Quart. Jour. Geol. Soc.*, XLVI (1890), p. 379.

[2] N. L. Bowen, "Crystallization-Differentiation in Igneous Magmas," *Jour. Geol.*, XXVII (1919), p. 393.

gested by Barrow. First, horizontal compression of a laccolith, crystallized to about 80 per cent, might yield an upper differentiate of liquid;[1] the effect on the crystallizing residue is clearly described as follows: "The horizontal dimensions are shortened in consequence of closer packing of crystals." Second, horizontal compression of a sheet in which the top and bottom had partly crystallized might result in a squeezing of the liquid into the central zone; here again the crystalline residue will have its horizontal dimensions shortened. Third, there may be a warping of the walls of a sheet; the forces which are expected to compress part of the sheet to such a degree that other parts are thickened are not described. It would seem that there is no reason to assume a *central* accumulation of the liquid in this case, any more than in the case of a laccolith, where an *upper* layer is supposed to accumulate. Both sheets and laccoliths have competent roofs. Both are likely to have their upper layers solidified early.

There are thus outlined three cases in which Bowen finds no mechanical difficulty in imagining an action like a filter press. Two fundamental objections may be raised and should be answered before final acceptance of the idea. The first has to do with the structures left in the crystalline mesh after expulsion of the fluid; the second is a matter of the completeness of the separation, and the volumes of the separated parts.

Structures.—These three types of filter-press action occur when the mass is 80 per cent or more crystalline. Such a mass would have the crystals pretty well locked together. Uniform spheres closely packed take up only about 75 per cent of the space in which they are packed. Packed angular grains may occupy as little as 50 per cent. Even 5 per cent further growth would result in a fairly firm bond between adjacent crystals. If now the mesh

[1] Bowen carries the idea too far when he attempts to apply it to the Duluth lopolith. Lateral thrust on a sunken basin would hardly tend to dome up the roof. Furthermore he makes an inaccurate copy of a map published with a plain statement that the area on which he bases his argument had not been mapped in detail.

EDITORIAL NOTE: In this connection it may be said that the map which Dr. Bowen states that he copied is the map printed as Fig. 6 in the *Journal of Geology*, Vol. XXVI, p. 446. The map which Dr. Grout apparently has in mind in this connection is the map reproduced as Fig. 1, Vol. XXVI, of the same *Journal*, p. 628. The differences between the two are very slight.

was deformed, the crystals would be broken and bent in rather violent fashion. Rock flowage would be evident in the examination of the grains. It is possible, of course, that the temperature is so high and conditions so favorable for recrystallization that some of the strain effects would later disappear, but the broken crystals of porphyries and such rocks as the Sudbury norite argue against such effects. Even if recrystallization occurred, the process would be accomplished under stress and an orientation of grain would be almost inevitable. It is worth while, then, to investigate the cases of supposed filter-pressing for signs of structure and deformation. It would be a strong confirmation of Bowen's argument if a laccolith or sill could be cited in which the fluxion structure corresponded to the position of such differentiates as he describes. Neither Bowen, Judd, Barrow, nor Harker makes any mention of such an orientation. On the contrary, in the illustrations of the glass supposed to have oozed into vesicles Judd and Harker show exactly the opposite orientation. It looks much more as if a lump of solid glass had interfered with the haphazard position of the crystals.

Turning to the special case of Duluth, Bowen takes up a final suggestion of the mechanics of filter-press action by proposing a theory to account for the rocks described.[1] The great lopolith shows a sunken structure at present, and on that basis it may be assumed that there were some movements during crystallization.[2] Bowen believes that movements when the mass is 50–65 per cent crystalline would tend to produce bands and layers by the bridging action of the feebly interlocked crystal mesh. The reality of the bridging effect in a crystal mesh need not be questioned, but a more detailed report of the experimental work which led him to the suggestion and to the estimate of 50–65 per cent of crystals would be welcome. He has previously[3] stated an opinion that a magma with 50 per cent crystals was eruptible, and the bridging effect was ignored.

[1] *Jour. Geol.*, XXVII, p. 411.

[2] The main subsidence must have occurred before crystallization, for the mass is too thick to be supported isostatically as a dome. It is not improbable, however, that movements continued.

[3] *Jour. Geol.*, Supplement, November-December, 1915, p. 31.

The effect of the bridging tendency in such a crystallizing magma is stated in Bowen's words; the liquid must flow "into the space immediately below it, if the potential bridge is to become a reality." It is a most significant point that the motion is at right angles to the bands, each crystallizing layer contributing liquid to form a layer just below or just above. Furthermore, the deformation produced in the "weak yielding segment" is from lateral compression. Both the flow and the deformation would produce a *vertical* orientation. As a matter of fact the bands in the Duluth gabbro show many instances of orientation parallel to the bands and not one at right angles. It should be noted also that any filter-press action at Duluth must have stopped before much interlocking of crystals occurred, for there is very little sign of broken or bent crystals—three or four grains in hundreds of sections. There are enough to show that signs of strain may be preserved, but are so few that no general deformation is likely. Here, as in the previous cases that Bowen outlines, the evidence of structure is emphatically opposed to the action he suggests.

Completeness of separation and volumes of the separates.—If we assume, as seems probable, that liquid may be squeezed out from a crystal mesh 50–80 per cent crystalline, how complete a separation can be effected? In the banded portion of the Duluth gabbro the main rocks are olivine gabbro with only slight changes in proportion of minerals, but the bands of extreme composition are just as truly bands as the rest, and are evidently formed in the same way. Can an anorthosite be squeezed out of the same olivine gabbro as a peridotite? Or must we assume that the peridotite was the *residue* after the average gabbro liquid was squeezed out? If we assume that peridotite is a residue, can we assume for a neighboring band that anorthosite was the residue after the same average gabbro was squeezed out?

Bowen notes that the contrast between bands should be of a different order of magnitude from that shown in the gabbro-granophyr association, implying that the variation in the bands is relatively slight. The bands vary from rocks 98 per cent plagioclase to rocks 90 per cent magnetite, and include peridotites with no

feldspar and troctolites with no augite. The extremes are 100 per cent different, and are not to be expected from filter-pressing.

Taking next the case of granite separated from gabbro, we find it a general rule that the separation has proceeded to such a degree that the granophyr diabase is very small in bulk.[1] Such action develops only after the magma is 80 per cent crystals. The occurrence of 300 feet of red rock above gabbro with practically no granophyr, as described at Duluth, should mean that over 1,200 feet of gabbro was almost completely drained of all 20 per cent residual fluid—so completely that the trifling residue left no determinable mineral and produced no zoning of the feldspars. Such thorough drainage from so large a mass seems very unlikely. And if the 80 per cent crystal mesh had any strength at all it must have refused to yield so completely as to leave no interstitial magma at all. Interstitial granophyr would be much more likely to be trapped among crystals than as blebs in an immiscible liquid.

SUMMARY

In igneous magmas the movements which are subject to some disagreement are convection, crystal settling, and the expulsion of residual magma from a partly crystalline mass. An attempt is made to remove certain misconceptions of the convection process and its effects. The process of crystal settling seems to be limited to effects which may be estimated to extend not over 100 feet. Attention is called to several difficulties in the application of the filter-pressing idea. The writer favors all three of the ideas as working hypotheses, but certain critical field relations should be sought for before accepting either in specific cases.

[1] Frank F. Grout, "A Type of Igneous Differentiation," *Jour. Geol.*, XXVI (1918), pp. 645–57.

DEFORMATION OF CRYSTALLIZING MAGMA

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In the foregoing paper Professor Grout raises certain objections to processes that I have advocated as significant in petrogenesis, and to some of these objections I wish to take the opportunity, offered by the editors, of making a brief reply.

With particular reference to the Duluth gabbro, Grout says that "the arguments for circulation are conclusive," but offers no further support for the arguments than that formerly offered. The banding and fluxion structures are conclusive evidence of circulation of a sort, perhaps, but not necessarily of convective circulation. Convection suffers from the disability of requiring the further assumption of rhythmic crystallization, i.e., crystallization which is periodic with respect to the nature of the substance crystallizing. In this manner it is hoped to obtain alternating layers of different composition, but it would seem much more probable that convection would effect a thorough mixing of the successive products. The rhythmical crystallization itself is, moreover, an assumption that has nothing to support it in the whole realm of crystallization phenomena. The Liesegang ring effect is a totally different affair, and any assumption of rhythm in crystallization, such as Grout pictures, should be made only *in extremis*.

On the other hand the down-warping of the tabular mass of crystallizing magma would seem to necessitate the development of fracturing along planes sensibly parallel to the tabular extension of the mass. The crystalline mesh would be subject to an action that is to all intents and purposes thrust-faulting along these planes. This action opens the possibility of the filling of the fault "fissures" with liquid from the interstices of that portion of the adjacent mesh that happens to be weakest and of developing layers

that have approximately the degree of contrast shown between crystals and residual liquid at the time the action takes place. It must be understood, of course, that the crystal mesh is very weak and not capable of sustaining open fissures, but that local crushing of the mesh, formation of "fissures," and their filling with liquid are absolutely synchronous.

Such action, oft repeated as the warping continued, would seem to be thoroughly competent to produce the banded structure; nor does it fall behind in ability to produce fluxion structures. The flow of liquid through the pores of the adjacent mesh would not be particularly directional, but in its action of filling the "fissure" it would spread laterally and crystals would be correspondingly oriented. At first thought one might ask: "What crystals?" but it can scarcely be doubted that the thrusting action pictured would result in tearing a multitude of crystals from their relatively insecure moorings along the walls of the thrust planes and in their distribution by the liquid filling the "fissures."

Both the banding and fluxion seem, then, to be readily accounted for by the warping of the mesh as described, but the full consequences of such action are not yet exhausted. The liquid filling the lenticular openings developed carries, as we have seen, a certain amount of crystals, and the alignment of these marks the fluxion structure, particularly where the lenses are thin. In thicker lenses settling of these already large crystals will immediately take place when they are heavy, and there may develop from their accumulation the most extreme of monomineralic layers. Moreover, the liquid, thus purged of its suspended crystals, begins to crystallize itself under conditions that could scarcely be more favorable for differentiation by crystal settling. The temperature gradient is exceptionally low for a liquid mass just beginning to crystallize. Slow cooling and freedom from convection, the arch enemy of differentiation, are thus assured and the extent to which sorting of crystals is carried as these quiet pools crystallize is not likely to be matched in any ordinary type of intrusion. Not only the normal bands of moderate contrast may be produced by this warping action, therefore, but also bands of the most extreme types as an ultimate consequence.

We may pass on now to a consideration of the squeezing out of liquid at a still later stage of crystallization to form a distinct differentiate such as a granophyre mass. The breakdown of the crystal mesh at this stage would still, I believe, be accomplished by fracturing along areas of contact between two adjacent crystals and subsequent revolving of the crystals into a position permitting closer packing. There is later, too, a further growth of crystals dependent upon the amount of liquid ultimately left in the interstices, and the final result would be a panidiomorphic granular (not granulated) mass showing normal crystallization textures. The production of broken crystals and of granulation belongs to a later stage, when there is a negligible amount of interstitial liquid and shearing forces of a much greater order of magnitude must be brought into action. In all probability such forces do come into play in the production of some anorthosites, but far-reaching results can be produced by filter-press action without any necessity for the development of granulation.

In the case of production of a granophyric body from gabbro magma by expressing of liquid, there is no necessity that the gabbro should show granophyric interstices, for if the cooling is slow enough the granophyric liquid that remains in the interstices may be used up and normally will be used up by reaction with crystals already separated. No one who has examined a section of a gabbro with granophyric interstices can have failed to see the reaction referred to, interrupted before completion. The reaction between relatively large blebs of granophyre produced by immiscibility, while it might be of the same nature, could not possibly be carried to completion.

In conclusion I wish to confess some surprise at Grout's statement that I have made an inaccurate copy of his map of the Duluth gabbro, for the copy was made for me by a competent draftsman. Furthermore, my surprise has been greatly increased on examining my map, going over it minutely with a pair of dividers and finding that it corresponds absolutely, dimension for dimension, with Figure 6 of his paper, "Internal Structures of Igneous Rocks."[1]

[1] *Jour. Geol.*, XXVI (1918), 446.

Reviews

Geologic Map of Brazil. By J. C. Branner. Geological Society of America. "Outlines of the Geology of Brazil With Map." Vol. XXX, pp. 189–338. 1919.

Branner's Geologic Map of Brazil (Plate I) covers an area as large as that of the United States between the 49th parallel and Mexico, approximately three million square miles. It is on the scale of 1:5,000,000 or 1 inch to 80 miles. It is thus a wall map similar in scale and scope to the Geologic Map of North America of 1911.

This important contribution to our knowledge of South America centers chiefly in the geologic map, to which the accompanying text, although it comprises 150 pages, is merely an accessory. The base map was prepared by Dr. Branner, who constructed it in accordance with all available geodetic data and the personal information which he had gathered, supplemented by the maps listed in the accompanying text. The geologic coloring represents the distribution of the major stratigraphic divisions completely and in some detail for the eastern states, stands for reconnoissance in the Amazon region and along the foothills of the Andes, but is lacking over the central plateau for an area of approximately 500,000 square miles. There are also some other lacunae representing the imperfections of even general information regarding the geology. One of the most conspicuous, because it occurs in an otherwise well-known part of the country, traverses Minas Geraes and Bahia and covers the line of contact between Lower and Upper Permian, which cannot be traced with accuracy in this strip.

The geology is sketched very broadly. Thirteen divisions of the geologic column are represented, namely:

13 Quaternary
12 Miocene and Pliocene
11 Eocene
10 Cretaceous
9 Igneous rocks of Mesozoic age
8 Triassic
7 Upper Permian
6 Lower Permian
5 Carboniferous
4 Devonian
3 Silurian
2 Early Paleozoic
1 Archean

It is obvious that there are large breaks in the sequence, due either to lack of knowledge or to unconformities. Both conditions exist. Geologic history is meagerly recorded in the great plateau of Brazil, which, in many respects, closely resembles the Laurentian Plateau of Canada and its marginal areas. Our knowledge of the record as far as it exists is also very incomplete.

The author says:

> In view of the limitations of our knowledge, it is not possible to represent on the map more than thirteen subdivisions of the geologic column. In some localities many more subdivisions are known and, over a limited area, might have been shown, but there would be no particular object in giving all of these subdivisions on a map of this scale. The minor details, even where they are known, are necessarily omitted on account of the small scale of the map. In regions of horizontal rocks, where partings are dendritic in form and outliers are abundant, these features cannot conveniently be shown. The areas of old crystalline schists are almost everywhere traversed by dikes of eruptive rock, but these dikes are usually too small to be shown on the map of the scale of this one. The same thing is true in the southern states, where numerous dikes cut all of the rocks below the Cretaceous.

The degree of generalization in classification in the map of Brazil is similar to that of McGee's geologic map of the United States (1884), but only a small portion of the map of Brazil is based on detailed topographic and geologic surveys like those which were available to McGee. Rather might we compare Branner's map with that of the United States by Marcou (1853)[1] or by Hitchcock and Blake (1874).[2] Dr. Branner himself has expressed the opinion that the geology of the United States was better known when Marcou published than is that of Brazil today. Branner's map is, however, far superior to Marcou's as a work in cartography, because of its rigid adherence to known facts, although it cannot be compared with Hitchcock's from the point of view of completeness of knowledge.

Judging by these criteria it is reasonable to state that knowledge of the geology of Brazil is more than half a century behind that of the United States. To a certain extent this may be attributed to physical difficulties, tropical vegetation, soil covering, and the general absence of fossils. But a more potent cause is the lack of general interest among

[1] Jules Marcou, "Résumé explicatif d'une carte géologique des Etats Unis et des provinces anglaises de l'Amerique du Nord, etc.," *Bull. de la Soc. Géol. de France Second Series*, Vol. XII, 1854–55.

[2] C. H. Hitchcock and W. P. Blake, Geologic Map of the U.S. in *Statistical Atlas*, Ninth Census, 1874.

the peoples of Brazil in geology, either from the scientific or the practical point of view. There are but few trained investigators in the country, and there is great need of adequate public sentiment to support either state or national surveys. Those far-sighted Brazilians who appreciate the importance of a knowledge of the geologic history and resources of their country advance but slowly against the lack of interest of the people and the inertia of the bureaucracy.

The scientific world will share with the author of this map the hope that his contribution to the world's knowledge of Brazil may stimulate interest among the people of that country in a truly scientific, thorough survey of their great domain. Many of the enlightened nations of the world are carrying on such a survey and regard its cost as a necessary charge on the national budget, because in the long run the advantage to the nation far more than outweighs the expense. It is, however, a mistake to assume that returns from the money invested in a geological survey are either evident or immediate. The principal object is to make and publish maps and reports which shall furnish reliable information regarding the country, and thus promote its development, increase its population, and augment its sources of revenue. Brazil greatly needs a well-organized topographic and geologic survey, such as can be executed only by a trained staff, in order to inform her own people and the world regarding her resources in agriculture, water powers, and mineral wealth, and also to promote the investment of capital on the sound basis of scientific knowledge.

The text accompanying the map includes an extensive bibliography of the sources of information which the author has discovered during what we may well call an exhaustive study of the subject. The list consists almost exclusively of the names of European and North American travelers and geologists. One of the earliest is von Eschwege, who occupied an official position in Brazil and wrote on the geology of the country just a century ago. Hartt, as head of the Geological Survey in the seventies, organized important investigations and himself made contributions to our knowledge, but he was rather a zoölogist than a geologist. His successor, Derby, who held the position as head of the Geological Survey up to the time of his death in 1915, stands officially for the principal work carried out under national auspices. With these should be named Dr. Gonzaga de Campos, a Brazilian geologist who has done much to advance the exploration of his country and is still in active service. There are many distinguished names in the list of investigators cited by Branner, but there is none who has brought to the

study an equal understanding of stratigraphic and structural problems or has pursued the investigation so persistently as has Dr. Branner himself.

In his foreword the author states:

> The accumulation of the data for the geologic map of Brazil was begun by me in 1874, when I first went to that country, and has been kept up as opportunities offered, down to the present time. The gathering and study of the material and the preparation of the map may therefore be said to represent the work of a considerable portion of a lifetime.

In addition to the large amount of information secured through his own personal observation the author has utilized the work of his several assistants, who have accompanied him on his expeditions to Brazil, and he has availed himself of every scrap of published or unpublished data which could stand the rigid scrutiny to which he subjected it. His resources in every direction have been unusual, but what stamps the map with authority is the character of its author, whose life-work in Brazil it epitomizes.

The geologic facts recorded in the map and accompanying text will serve three classes of students. Those who are interested in the history of Brazil as an example of the geological development of a great continental nucleus will find in the summary comprised under "Outlines of Stratigraphic Geology," pp. 202–23, a brief but comprehensive statement. Those students who may be interested in the geology of individual states or in local details will turn to the general geology described by states in alphabetical order, and to the bibliography which follows the statement regarding each state; and those who are chiefly interested in the economic resources will find valuable notes also under the separate articles regarding individual states.

Branner's text is in itself a summary. As may be seen by reference to the extensive bibliographies accompanying the descriptions of the several states, a full discussion would constitute a large volume. In order, however, to indicate the general facts of the geology in bare outline the summary may be summarized as follows:

The Brazilian complex, or basement, of the Brazilian plateau of South America is a mass of crystalline metamorphic and eruptive rocks, granites, gneisses, and schists, which closely resembles the Archean complex of the Canadian shield. They constitute the surface in the eastern mountain ranges and plateaus, forming a broad belt all along the Atlantic Coast, except in the far south. They occur both north and south of the geosyncline of the Amazon Valley, and outcrop at numerous

points in the plateau of Matto Grosso. Occurring either in these rocks or derived from them are gold, copper, platinum, tungsten, mica, marble, talc, apatite, graphite, potash-bearing rocks, precious stones, and building stones.

Distinctly younger than the Brazilian complex or Archean is a sequence of metamorphic rocks of unquestionable sedimentary origin, consisting of quartzites, schists, limestone, and the great iron-bearing formations of Minas Geraes. These strata occur imbedded in the Archean, which unconformably underlies them and by which they are in part covered in consequence of overthrusting. Their age is indeterminate, as no traces of fossils have been found, but they are assigned by Branner to the early Paleozoic.

It is evident that a period of profound diastrophism intervened between the deposition of these "early Paleozoic sediments" and the next succeeding strata, which are sandstones of Silurian (Niagara) age. To the systematic geologist it is a question of some importance whether the deformation occurred in the early Paleozoic or possibly in pre-Paleozoic time, as might be the case if the metamorphosed sediments belonged to the pre-Cambrian. It would seem that we have here a problem not unlike that of the later pre-Cambrian formations of the Lake Superior region which, by some geologists, are considered to include Cambrian rocks.

These ancient metamorphosed strata are economically of very great importance. They include the enormous iron deposits and the important occurrences of manganese. Gold-bearing veins occur in them, and the diamonds and other precious stones of Brazil are supposed to have been derived from them.

The Silurian sandstones already referred to are the oldest fossiliferous rocks known in Brazil. They are of Niagaran age and occur on the northern side of the Amazonian geosyncline, dipping gently southward. Branner expresses the opinion that it is highly probable that there are rocks of Silurian age in other parts of Brazil, but none have as yet been identified by fossils.

Strata of Devonian age occur at widely separated points in Brazil. They are found north of the Amazon, in São Paulo and Paraná in the south, and in Matto Grosso in the west. They consist of white and yellowish sandstone and black and reddish shales. In the Amazon region, although they dip at a very low angle and are not otherwise disturbed, they are cut by dikes of diabase. In Paraná and southern São Paulo the Devonian rocks seem to rest directly on the Brazilian

complex and dip gently westward beneath the Permian. They consist of conglomerates, sandstones, and shales, and the conglomerates of Paraná are supposed to be the source of the diamonds of that state.

Upper Carboniferous beds, containing marine fossils, are exposed in the state of Pará and also in Amazonas, north of the Amazon River. They are shales, sandstones, and limestones, aggregating about 600 meters in thickness, but they contain no coal. In Bahia certain quartzites, sandstones, and conglomerates which yield diamonds and carbonados are doubtfully assigned to the Carboniferous. Branner discusses in some detail the relation between these diamond-bearing strata of Bahia and the diamond-bearing quartzites of Minas, and inclines to the opinion that they are stratigraphically equivalent. The Carboniferous rocks are not now known to contain other resources of economic significance.

The pre-Permian Paleozoic strata, which have been briefly described, appear to be restricted to somewhat local occurrences and to represent a moderate degree of sedimentation. It would seem as though Paleozoic history in Brazil had been characterized by very gentle movements of uplift and depression and correspondingly scanty erosion. The Permian, on the contrary, is composed of two widespread series Lower and Upper Permian, each of very considerable thickness. A belt of Permian rocks from 100 to 500 miles wide, more or less, extends from near the Atlantic Coast east of the Amazon, southward continuously through all the intervening states, to Santa Catharina, a distance of 2,000 miles. East of it lies an even broader belt and one of equal length, consisting of the Brazilian complex and the infolded Paleozoic rocks. The latter constitutes the Atlantic Coast ranges of Brazil and the eastern part of the Brazilian plateau, while the Permian rocks form the surface of the plateau farther west. The Permian rocks were apparently deposited in a great geosyncline, which developed in the strip where they now occur along the western base of a mountain range that furnished the materials for the sandstones and shales. There is thus evidence that eastern Brazil was mountainous in Permian time as it is today, and there is a certain parallelism between the orogenic structure of eastern South America and that of the eastern United States in Permian time.

Branner summarizes the description of the Permian of Brazil, saying that the rocks "seem to be mostly sandstones and shales, slightly disturbed, but they include extensive beds of limestone—all of them cut here and there by eruptive dikes. In São Paulo, Paraná, and Santa Catharina the Lower Permian contains glacial till with striated boulders."

He discusses at some length the evidences of the age and extent of the Permian glaciation, and cites the observations of a number of geologists and travelers upon the occurrence of the strata and fossils by which they have been identified. He distinguishes the Upper and Lower Permian, both in his text and on the map, except that he has not indicated the boundary between the two where its location is not definitely known, on the headwaters of the Rio São Francisco. The Upper Permian is described as unconformable upon the Lower, but the break is marked only by a change in sedimentation.

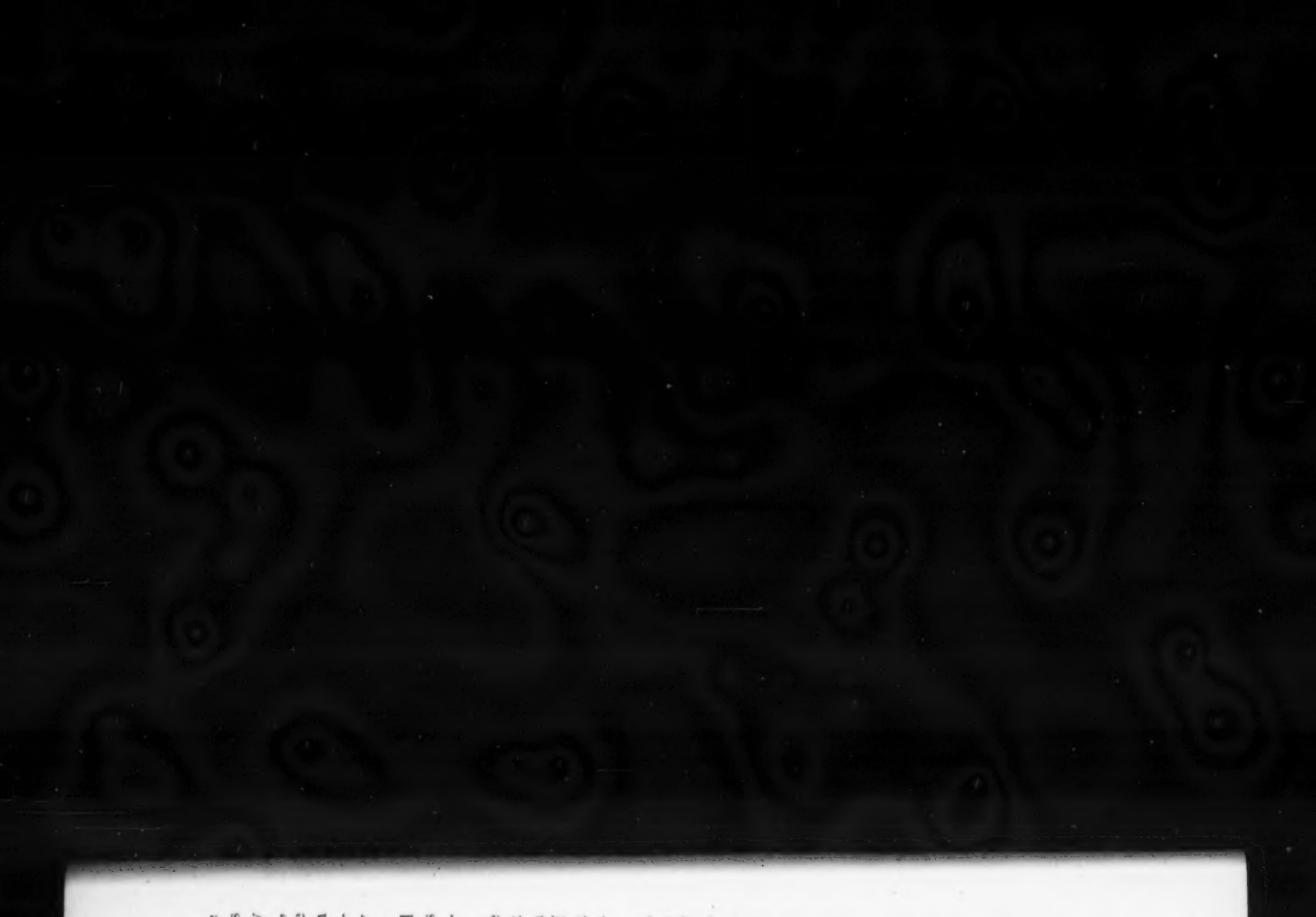
The coal beds of Paraná, Santa Catharina, and Rio Grande do Sul are economically important, as are also the Permian bituminous shales of the southern states. The limestones will yield materials for the manufacture of Portland cement.

The pre-Mesozoic rocks, including the Permian, constitute the mountains and plateaus of all of eastern Brazil, which is thus a great geologic province whose history since the close of the Paleozoic has been that of a continental area subject to erosion. With the exception of small areas of Tertiary rocks along the Atlantic Coast and an embayment of Cretaceous and Tertiary strata in Bahia and Piauhy there are no post-Paleozoic sediments in the area.

The Mesozoic rocks occur southwest and west of the great Brazilian plateau. They comprise the red sandstones of the Trias, extensive outflows of pre-Cretaceous igneous rocks, and sandstones and limestones of Cretaceous age. The Trias is most widely represented in western São Paulo and southern Goyas. The igneous rocks, erupted through the Trias and spreading out as very extensive lava flows similar to those of the Columbia lavas, occur in Rio Grande do Sul, Santa Catharina, Paraná, and São Paulo. They occur as interbedded sheets exposed along the canyon of the Paraná, where, on account of the small scale, the coloring of the map gives an appearance of a widespread igneous mass under the Trias.

The Cretaceous is distributed in the form of remnants capping the Triassic plateaus, and extends northwest across Matto Grosso to the Andes and also north to the Amazon Valley. In the northwest and north it appears to rest directly upon the Brazilian complex, the older rocks being absent.

The Tertiary formations of Brazil are briefly described as comprising freshwater and land deposits of the territory of Acre, brackish water deposits in Amazonas, and marine deposits in Pará, Maranhão, and also in Rio Grande do Norte. Marine Tertiary occurs along various sections



VENEZUELA
COLUMBIA
GUYANA INGLEZA
GUYANA
GUYANA FRANCEZA
HOLLANDEZA
ECUADOR
MAPPA GEOLOGICO
DO
BRAZIL
JOHN CASPER BRANNER
1915

PERU
BOLIVIA
ARGENTINA
CHILE
PARAGUAY
URUGUAY
LEGEND

of the coast, and Tertiary lake beds are found in Rio de Janeiro, São Paulo, and Minas.

Following the systematic summary of the geologic series represented in Brazil, Branner gives a fuller account of the geology of each province, and with it a bibliography of the works of travel and scientific exploration describing that state. The outline concludes with statements regarding the economic resources and mining laws of Brazil.

It was not the author's purpose to give a full discussion of the geology of Brazil. He refers, on the contrary, constantly to the original documents upon which he has drawn to supplement his own personal knowledge.

Dr. Branner has, with the aid of the Geological Society of America, made a very important and fundamental contribution to the geology of South America. The Society is to be congratulated upon the service it has thus rendered to science. The author also is to be felicitated, but he has the deeper satisfaction of having achieved the purpose of a lifetime, of having laid the foundations of the geology of Brazil firmly in an exact account of the present state of knowledge.

NOTE.—The *Outlines of the Geology of Brazil* with the geologic map is published in the usual edition for the use of the Society, in English, and in a Portuguese edition of 1,000 additional copies. There are also 500 extra copies of the map. It is regrettable that the number of copies of the text and map available to the general public is so limited.

In many paragraphs the reader will be embarrassed by the lack of any means of identifying the localities named. It was not possible to put all the names or any large part of them on the map. Neither do they all occur on maps contained in the usually available atlases. An index of place names, giving the location by latitude and longitude, would have been of great assistance.

Translations of the quotations which are given in the original languages, notably of the Portuguese, would have helped many readers.

BAILEY WILLIS

EXPLANATION OF PLATE XII

The accompanying map is a reduced photograph of the original and, in order to make it legible, numbers have been inserted on the principal areas of the different formations. The following is the list of formations distinguished:

13. *Quaternary.*—Alluvial deposits, stone reefs of the northeast coast, and the sandstones of Fernando de Noronha.

12. *Miocene or Pliocene.*—Tertiary of the upper Amazon, the coast and lake beds of Minas, São Paulo, Bahia, and Rio de Janeiro. Catinga limestones, Bahia.

11. *Eocene.*—Maria Farinha, Olinda, Pernambuco, Alagoas, Piabas, Maranhão, Natal, and the coast.

10. *Cretaceous.*—Sergipe, Bahia, Serra do Araripe, Ceará, Parahyba. Parecis beds of Matto Grosso. Baurú of São Paulo (Wealden) Marahú Bahia. São Bento series of Santa Catharina.

9. *Igneous Rocks.*—Pre-Cretaceous igneous, alkaline rocks and their associates, including nephelene syenite, foyaite, tinguaite, phonolite, syenite, trachyte, gabbro, diabase, diabase-basalt, and the Triassic "trap" of the southern states.

8. *Triassic.*—Maracajú of southern Matto Grosso; Botucatú of São Paulo; Rio do Rasto of Santa Catharina; Santa Maria, Rio Grande do Sul with Scaphonyx.

7. *Upper Permian.*—Passa Dois series of Santa Catharina, Stereosternum and Mesosaurus beds with cherty concretions of São Paulo. Piauhy, Bahia (Aricy); Estancia beds of Sergipe, Maranhão e Goyaz (Psaronius beds), Matto Grosso.

6. *Lower Permian.*—Tubarao series of Santa Catharina; coal beds of southern states with Glossopteris flora; glacial beds, Orleans conglomerate. Serra Grande series of Piauhy and Ceará of Small. Salita Limestones, Bahia Limestones of Rio das Velhas.

5. *Carboniferous.*—Marine beds of Rio Uatuma, Frechal e Pedra do Barco in Amazonas; Itaituba, Trombetas, Maecurú and Curuá, Para; Lavras quartzites of Bahia.

4. *Devonian.*—Ereré (above), Maecurú and Curuá in Amazon valley. Ponta Grossa shales in Paraná; Chapada in Matto Grosso; Caboclo shales, Bahia.

3. *Silurian.*—Rio Trombetas, state of Pará. Tombador in Bahia Cuyabá slates, etc.

2. *Early Paleozoic.*—Itacolumite? Iron manganese and schists of Minas Geraes; quartzites of Serra de Jacobina and elsewhere in Bahia. Lisboa's Bodoquena of Matto Grosso.

1. *Archean.*—Brazilian complex: gneiss, schists, granite.

Quicksilver in 1918. By F. L. RANSOME. Mineral Resources of the United States, 1880. U.S. Geological Survey.

There were no events of conspicuous importance or unusual interest in the quicksilver industry in 1918, but Dr. Ransome's annual review of the industry for that year is noteworthy not only as an excellent concise review of the industry, but because it contains a twelve-page list

of all of the quicksilver mines of the United States, giving their location, name and address of owner, general character of the deposit, nature and extent of the workings, reduction equipment, and estimated production to the end of 1918.

The report closes with a list of recent publications on quicksilver in the United States, Canada, and Mexico.

E. S. B.

Peat in 1918. By C. C. Osbon. Mineral Resources of the United States, 1918. U.S. Geological Survey.

The peat industry, though still one of our smallest mineral industries, exhibited somewhat surprising growth in 1917 and 1918, attaining in the latter year a production record about three times that for any year prior to 1917. This growth has been due partly to an increase in its use for fuel, especially in New England, but also to the development of other uses, such, for example, as its incorporation in commercial fertilizers and its use in the preparation of stock foods, partly as an absorbent for other components, but also because of its nitrogen content, which averages about 2 per cent. During the war over half a million absorbent surgical dressings were made in this country from peat moss and sent to our armies. The report constitutes an excellent brief review of the origin and distribution of peat in the United States and includes a map, 18×28 inches, showing in colors the distribution of our peat deposits and the location of peat-producing plants.

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